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ORTHOPÆDIC SURGERY OF INJURIES

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OXFORD MEDICAL PUBLICATIONS

ORTHOPÆDIC SURGERY OF INJURIES

BY VARIOUS AUTHORS

EDITED BY

SIR ROBERT JONES, K.B.E., C.B., F.R.C.S.

DIRECTOR OF ORTHOPÆDICS, ST. THOMAS'S HOSPITAL
SURGEON, ROYAL NATIONAL ORTHOPÆDIC HOSPITAL
CONSULTING ORTHOPÆDIC SURGEON, ROYAL INFIRMARY, LIVERPOOL
HON. ADVISER TO THE MINISTRY OF PENSIONS (ORTHOPÆDIC SURGERY)

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VOLUME II

ANATOMY OF THE PERIPHERAL SPINAL NERVES

BY

A. M. PATERSON

ANATOMY OF THE PERIPHERAL SPINAL NERVES

THERE are thirty-one pairs of spinal nerves, eight cervical, twelve thoracic, five lumber, five sacral, and one coccygeal.

Each takes origin from the spinal cord by two roots, one dorsal, afferent, and ganglionic, the other ventral, efferent, and non-ganglionic.

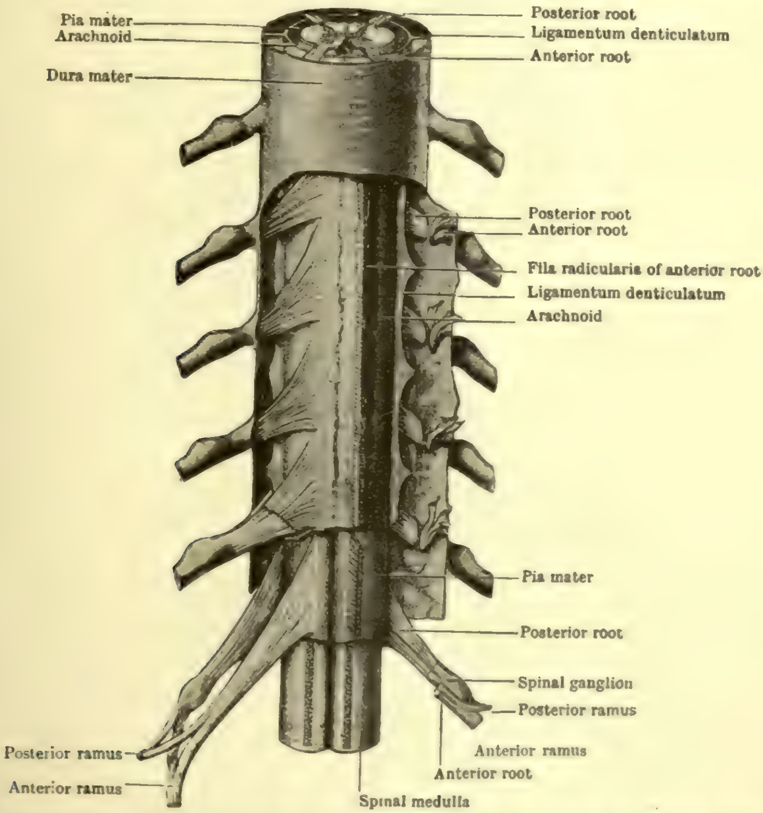


FIG. 1.—The membranes of the spinal cord and the roots of the spinal nerves.

The two roots pierce the envelopes of the spinal cord independently and unite in the neighbourhood of the intervertebral foramina, where they are enclosed together by a sheath of dura mater, to form the 'mixed' spinal nerve (Fig. 1).

The ganglia on the dorsal roots of the nerves occupy the intervertebral foramina except in the case of the lower spinal nerves, the roots of which are prolonged within the spinal canal to form the cauda equina. The dorsal ganglia of these nerves lie within the spinal canal.

Each spinal nerve lies below the corresponding vertebra, except the first cervical, which emerges between the occipital bone and the atlas.

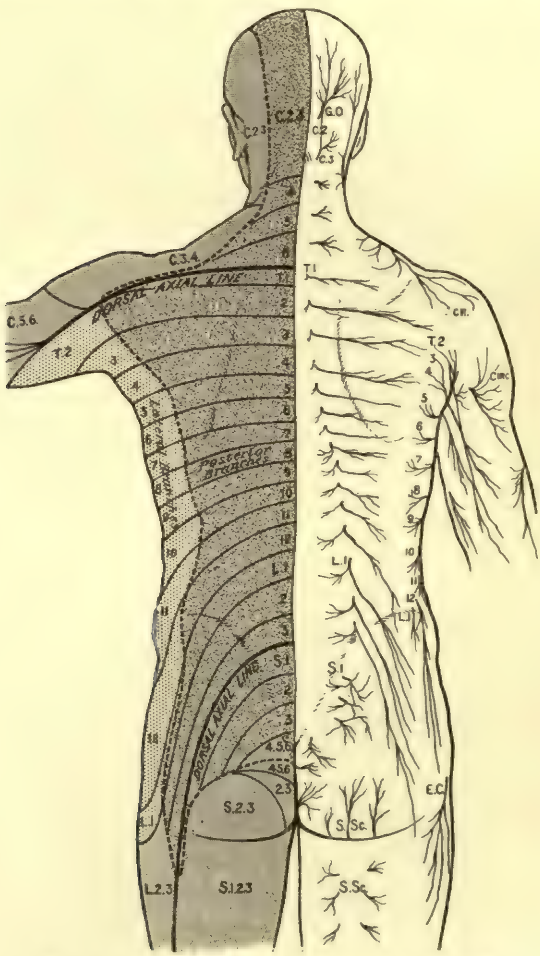


Fig. 2.—Innervation of the skin of the back.

Each nerve after emerging from the spinal canal divides outside each intervertebral foramen into smaller and larger branches—the posterior and the anterior primary division. Each division is composed, as a rule, of elements derived from each spinal nerve root—afferent and efferent, sensory and motor elements.

THE POSTERIOR PRIMARY DIVISIONS.

The posterior primary divisions supply collectively the axial muscles and the skin of the back. Each divides into an external and internal branch, of which one supplies skin and the other muscles. In the upper half of the back the muscles are supplied by the external branches, in the

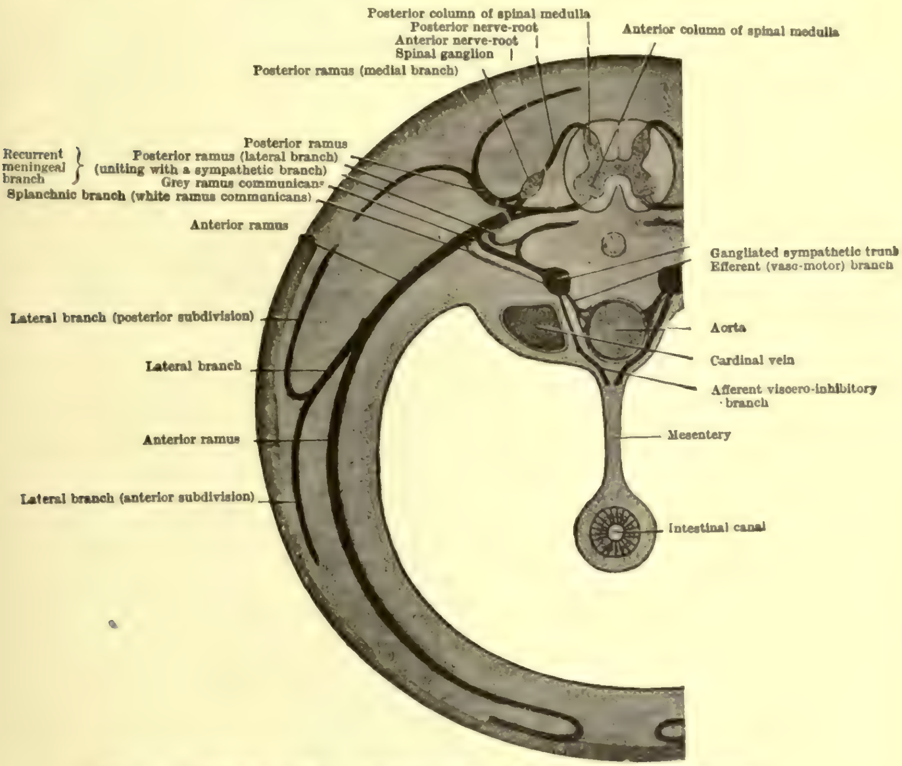


FIG. 3.—Scheme of the distribution of a typical spinal nerve.

lower half by the internal branches. In the upper half of the back the skin is supplied by the internal branches, and in the lower half by the external branches of the nerves. No cutaneous branches are given off by the first, seventh, and eighth cervical nerves, or by the fourth and fifth lumbar nerves.

It is noteworthy that in cutaneous distribution the posterior primary divisions are drawn into regions into which they do not strictly belong. For example, the second and third cervical nerves (**great** and **least** occipital) are carried on to the back of the scalp to supply it. The lower cervical and upper thoracic nerves innervate the scapular region, while the first three lumbar nerves innervate a considerable area of the buttock (Fig. 2).

Nerve Plexuses, in connexion with the posterior primary divisions.

Elementary nerve plexuses occur in connexion with the posterior primary divisions of certain nerves. The **posterior cervical plexus** is formed by loops joining together the first four cervical nerves, from which

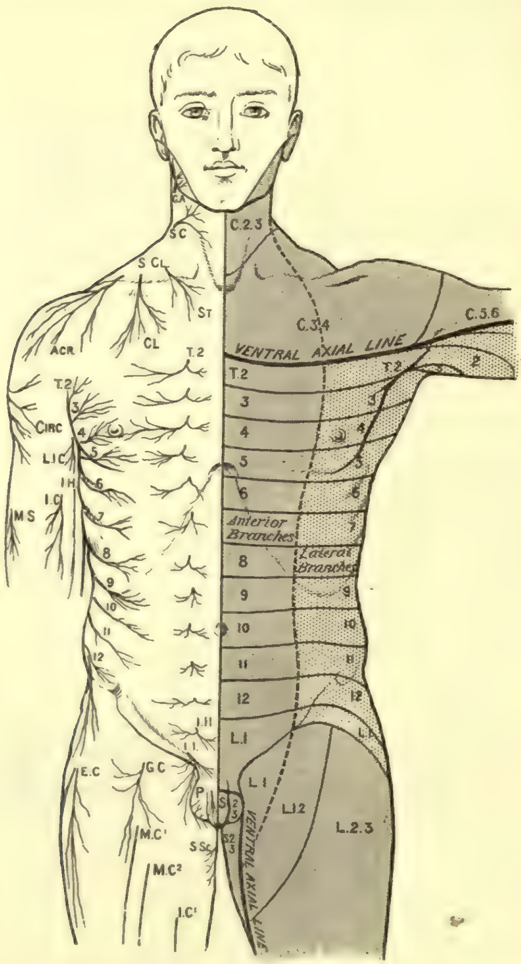


FIG. 4.—Distribution of nerves to the skin of the trunk.

branches pass to supply the muscles of the back of the neck. Similar loops connect the posterior primary divisions of the last lumbar and first four sacral nerves, from which branches pass to supply the skin over the back of the sacrum.

THE ANTERIOR PRIMARY DIVISIONS.

The simplest form of anterior primary division is to be found in the thoracic region (T 3–11). These nerves sweep round the body wall in the intercostal spaces to supply the muscles and skin of the thoracic and abdominal wall (Fig. 3).

Each is connected to the sympathetic system by grey and white rami communicantes. Each gives off a considerable **lateral branch** which

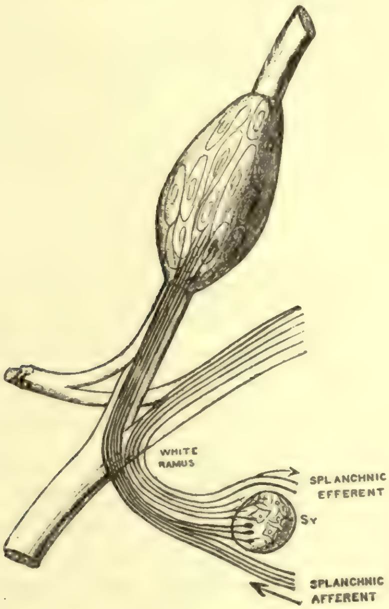


FIG. 5.—Connexion of spinal nerves and sympathetic system.

supplies the muscles of the chest and abdominal walls, and divides into two subordinate branches, anterior and posterior, for the supply of the skin of the side of the trunk. The part of the nerve remaining after the origin of the lateral branch is the **anterior trunk.** This passes forwards, and after supplying muscles, ends as a small cutaneous branch for the skin of the front of the chest and abdomen (Fig. 4).

The nerves supply continuous belts of skin, innervated by the posterior primary divisions, the lateral and anterior branches of the anterior primary divisions respectively.

The upper thoracic nerves are limited in their distribution to the walls of the thorax (C 3–7). The lower nerves, after passing through the wall of the chest, traverse the abdominal wall, lying first between the obliquus

internus and transversalis; after piercing the posterior lamella of the aponeurosis of the obliquus internus they pierced the rectus abdominis muscle and the anterior layer of its sheath, to become cutaneous.

Connexions with the Sympathetic System.

The white rami communicantes and the grey rami communicantes are the means of connexion of the spinal nerves and the sympathetic cord.

The **white rami communicantes** occur in two series:

1. **Thoracico-lumbar Rami.** All the thoracic and lumbar-spinal nerves give off white rami communicantes, which pass into relation with the sympathetic system.

2. **Pelvic or Sacral Rami.** The second and third or third and fourth sacral nerves give off white rami which pass inwards, but instead of joining the pelvic sympathetic cord they pass over the cord and join the pelvic plexus.

Each white ramus is composed of medullated fibres, derived from each spinal nerve root, afferent or efferent. The afferent fibres are viscero-inhibitory and join the dorsal ganglia. They innervate the viscera, and pass through the gangliated cord of the sympathetic. The efferent fibres pass into the gangliated cord, and become connected with the cells of the ganglia. From the ganglia again fibres emerge which are non-medullated and are the vaso-motor fibres for the visceral vessels.

The **grey rami** are essentially branches directed centrally from the sympathetic gangliated cord. Irregular in their disposition, they arise from the ganglia of the cord, or from the commissure, and are distributed to the anterior primary division of each spinal nerve. Some fibres are recurrent to the roots of the nerves. Most travel with the anterior primary divisions and become peripheral vaso-motor and pilo-motor nerves.

The Plexuses.

Excluding the spinal nerves referred to above, the remaining nerves are concerned in forming four important plexuses—cervical, brachial, lumbo-sacral, and pudendal.

The **cervical plexus** is formed by the first four cervical nerves, and is mainly concerned in supplying muscles and skin of the neck (Fig. 6).

The nerves in question form a series of loops under cover of the sterno-mastoid muscle at the side of the neck. Either from these loops or from the individual nerves a series of branches arise which may be classified as follows:

Superficial :

(*a*) Ascending :		
Small occipital	. . . .	(C 2, 3)
Great auricular	. . . .	(C 2, 3)
Superficial cervical	. . .	(C 2, 3)
(*b*) Descending : (supraclavicular)		
Sternal	. . . . .	(C 3, 4)
Clavicular	. . . . .	(C 3, 4)
Acromial	. . . . .	(C 3, 4)

Deep :

(*a*) External :		
(1) Muscular :		
Sterno-mastoid	. . . .	(C 2)
Trapezius	. . . . .	(C 3, 4)
Levator scapulæ	. . . .	(C 3, 4)
(2) Communicating :		
To spinal accessory	. . .	(C 2, 3, 4)
(*b*) Internal :		
(1) Muscular :		
Prevertebral muscles	. . .	(C 1, 2)
Phrenic	. . . . .	(C 3, 4)
(2) Communicating :		
Vagus	. . . . .	(C 1, 2)
Sympathetic	. . . .	(C 1, 2)
Hypoglossal	. . . . .	(C 1, 2)
Communicantes hypoglossi	. .	(C 2, 3)

The superficial group of nerves is wholly cutaneous, while the deep branches are mainly muscular in their distribution.

The **Superficial Branches** supply an area of skin, including the side of the neck, the scalp, lower part of pinna and face, and the front of the chest down to the level of the nipple, as well as the upper half of the deltoid region.

The deep branches innervate the following muscles :

Sterno-mastoid	. . . .	(C 2)
Trapezius	. . . . .	(C 3, 4)
Levator scapulæ	. . . .	(C 3, 4)
Prevertebral muscles	. . .	(C 1, 2)
Diaphragm (Phrenic)	. . .	(C 3, 4)
Sternohyoid, Sternothyroid, Omohyoid	(Ansa hypoglossi) .	(C 1, 2, 3)

The nerves to the sternomastoid and trapezius communicate with the spinal accessory nerve. Those to the trapezius cross the posterior triangle of the neck. The branches to the levator scapulæ come off directly from the anterior primary divisions of the third and fourth cervical nerves and enter the superficial surface of the muscle.

The first and second cervical nerves form a loop over the atlas from which branches pass to supply the prevertebral muscles, and to form communications with the sympathetic, vagus, and hypoglossal.

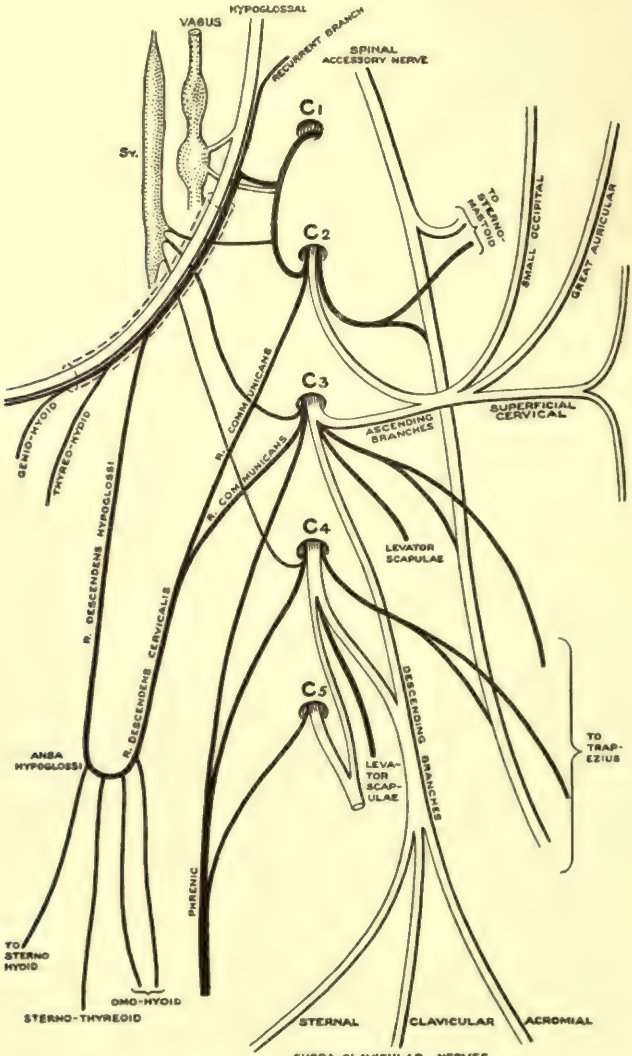


FIG. 6.—The cervical plexus.

Ansa Hypoglossi. The trunk from the first and second cervical nerves communicating with the hypoglossal nerve is of considerable size. It is incorporated with the hypoglossal, and becomes responsible for the following nerves (in order): recurrent branch, descendens hypoglossi, nerve to the thyrohyoid muscle, and nerve to the geniohyoid. The two

latter muscles are thus supplied by the first and second cervical nerves.

The **Descendens Hypoglossi nerve** passes down the neck in front of the external and common carotid arteries. It is joined by the **Descendens Cervicis**, a nerve which is formed by the **Communicantes Hypoglossi**—branches of the second and third cervical nerves—and which passes obliquely inwards over the internal jugular vein and unites with the descendens hypoglossi to form the **Ansa Hypoglossi**—a loop from which branches supply the infrahyoid muscles—sternohyoid, sternothyroid, and omohyoid (Fig. 6).

The **phrenic nerve** is formed by the third and fourth cervical nerves (joined by a branch from the fifth). It passes down through the neck, lying deeply on the scalenus anticus muscle. After traversing the thoracic cavity it pierces the diaphragm and supplies it on its under surface.

The Limb Plexuses.

A. Brachial Plexus.

The nerves of distribution to the upper limb are formed by the Brachial Plexus. The plexus is situated in the posterior triangle of the neck and in the axilla. The nerves composing the plexus are the anterior primary divisions of the last four cervical nerves, and the greater part of the first thoracic. The cervical nerves increase in size from above downwards. A small branch of communication passes from the fourth to the fifth cervical, and in the majority of cases there is a considerable intrathoracic communication between the second and first thoracic nerves.

The first thoracic nerve, after supplying a small intercostal branch for the supply of the muscles of the first intercostal space, and receiving a trunk of communication from the second thoracic nerve, passes over the first rib and becomes closely associated with the eighth cervical nerve between the scalene muscles.

The constituent nerves emerge in the neck between the scalenus anticus and scalenus medius muscles, in close relation to the subclavian artery. The fifth, sixth, and seventh nerves are above, and the eighth cervical and first thoracic are directly behind the artery.

There are four stages in the formation of the plexus and the nerves of distribution :

(1) The junction of the five separate nerves into three definite trunks. The fifth and sixth cervical nerves join together to form the upper trunk ; the seventh runs by itself as the middle trunk ; and the eighth cervical and first dorsal are united into the lower trunk.

(2) The subdivision of the trunks into anterior and posterior divisions.

(3) The reunion of these divisions into three cords. The anterior

divisions of the upper and middle trunks unite to form the outer cord; the anterior division of the lower trunk runs alone as the inner cord; and the posterior divisions of all the trunks unite to form the posterior cord.

(4) The formation of collateral and terminal nerves of distribution to the limb from these cords.

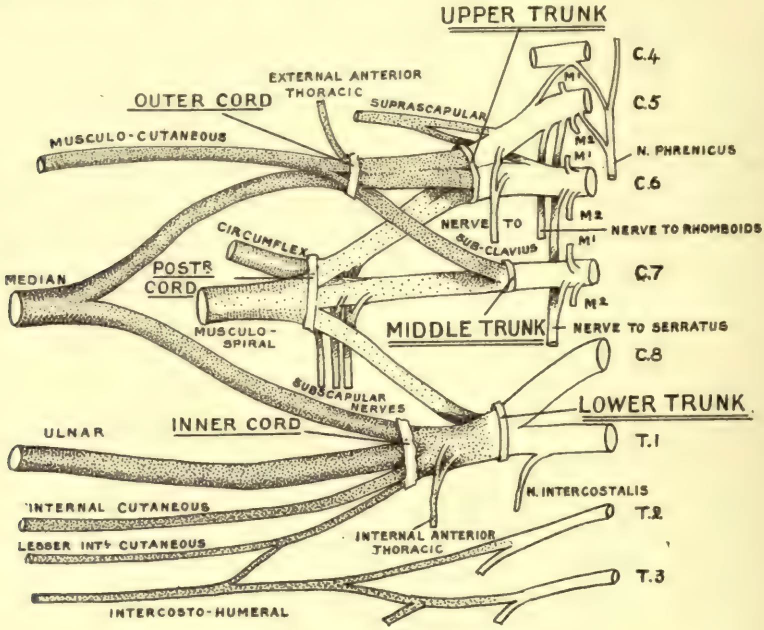


FIG. 7.—The brachial plexus.

In reality each nerve **retains its individuality** in these cords, and subdivides and again re-unites, by means of its subdivisions, with neighbouring nerves, to produce collateral and terminal branches of distribution.

Nerves of Distribution.

A. Collateral Branches.

In addition to the terminal branches distributed to the upper limb, two series of collateral branches are given off by the nerves forming the plexus—one set above and one below the clavicle.

1. Supraclavicular Branches.

These are six in number, and can be grouped in two series—anterior and posterior.

(*a*) **Anterior Branches.** (1) From the anterior primary divisions of the lower four cervical nerves **muscular branches** are given off to the

neighbouring axial muscles: longus colli, rectus capitis anticus major, and scaleni.

(2) **Communication with the Phrenic Nerve.** The phrenic nerve formed from the third and fourth cervical nerves is reinforced by a branch from the fifth.

(3) **Nerve to the Subclavius.** This small nerve is formed by the union of two roots from the front of the fifth and sixth cervical nerves. It passes down to the muscle in front of the subclavian vessels.

(*b*) **Posterior Branches.**—(4) **Suprascapular Nerve.** This is the most cephalic of the branches of the brachial plexus. It is a considerable nerve derived from the fifth and sixth cervical nerves. Passing behind the plexus it goes through the suprascapular foramen, and is distributed to the supraspinatus and infraspinatus muscles.

(5) **Nerve to the Rhomboids.** This nerve arises from the fifth cervical nerve, pierces the scalenus medius, and passes beneath the levator scapulæ on its way to supply the rhomboid muscles. It supplies a branch to the levator scapulæ muscle.

(6) **Posterior Thoracic Nerve** (Nerve to the serratus, external respiratory nerve of Bell). This nerve is formed by three roots from the back of the fifth, sixth, and seventh cervical nerves before their emergence between the scalene muscles. Piercing the middle scalene muscle below the nerve to the rhomboids it descends behind the axillary artery into the axilla, where it supplies branches to each serration of the serratus magnus muscle.

2. Infraclavicular Branches.

These are also six in number, and like the supraclavicular and terminal branches are derivatives of the anterior and posterior component trunks of the plexus.

The anterior trunks contribute two nerves, the posterior trunks four nerves, to the series.

(*a*) **Anterior Nerves.** (1) External and (2) Internal anterior thoracic nerves. These are the nerves supplying the two pectoral muscles.

The **external anterior thoracic nerve** is derived from the outer cord, and receives contributory roots from the fifth, sixth, and seventh cervical nerves. The **internal anterior thoracic nerve**, from the inner cord, receives its roots from the eighth cervical and first thoracic nerves (Fig. 8).

The pectoralis major is supplied by fibres which have a numerical sequence. The most cephalic fibres of the muscles are supplied by the highest, and the most caudal fibres by the lowest, nerves in the series.

The two nerves form a loop of communication over the axillary artery, from which branches pass to the pectoralis minor, after piercing which they end in the pectoralis major.

(*b*) **Posterior Nerves.** Four collateral branches arise in the axilla from the posterior cord—the circumflex, and the short, lower, and long subscapular nerves.

(3) **The circumflex nerve** is formed by the fifth and sixth cervical nerves. Enclosed at first in a sheath common to it and the musculo-spiral nerve, it becomes separate at the outer border of the subscapularis muscle. Accompanied by the posterior circumflex artery the nerve winds round the surgical neck of the humerus, in a quadrilateral space, bounded by the humerus and scapular head of the triceps, the subscapularis, and teres major muscles. Reaching the outer side of the arm, under cover of the deltoid, it ends by supplying that muscle.

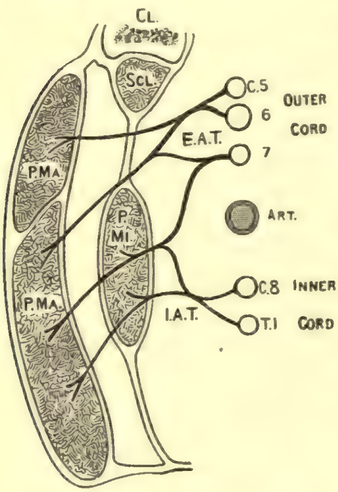


FIG. 8.—Innervation of the pectoral muscles.

The circumflex nerve gives off three branches in the following order:

(*a*) A small branch to the shoulder joint.

(*b*) A nerve to the teres minor muscle, characterized by the possession of a pseudo-ganglionic enlargement.

(*c*) A considerable cutaneous branch, which sweeps round the posterior border of the deltoid muscle, at the junction of its middle and lower thirds, and supplies the skin of the lower part of the deltoid region, and the outer side of the upper arm (Fig. 9).

(4) **Short Subscapular Nerves.** There are usually two short subscapular nerves, closely associated, in their origin from the back of the fifth and sixth cervical nerves, with the origin of the circumflex. They innervate the higher part of the subscapularis muscle.

(5) **Lower Subscapular Nerve.** This nerve is also closely associated with the origin of the circumflex, and is derived from the fifth and sixth cervical nerves. It accompanies the subscapular artery in a part of its course, and is the most external of the subscapular nerves. It is intermediate in length between the short and long subscapular nerves. It is distributed to the lower fibres of the subscapularis, and to the teres major muscle.

(6) **Long Subscapular Nerve.** This nerve is closely associated at its origin with the origin of the musculo-spiral nerve. It arises as a rule from the sixth and seventh, or sixth, seventh, and eighth cervical nerves, and it is distributed to the latissimus dorsi muscle.

B. Terminal Branches.

Distribution of the Nerves to the Upper Limb.

There are two series of nerves of distribution to the upper limb—terminal branches of the brachial plexus—one anterior, the other posterior.

They are six in number. Five are derived from the outer and inner cords, and one, the musculo-spiral, from the posterior cord (Fig. 7).

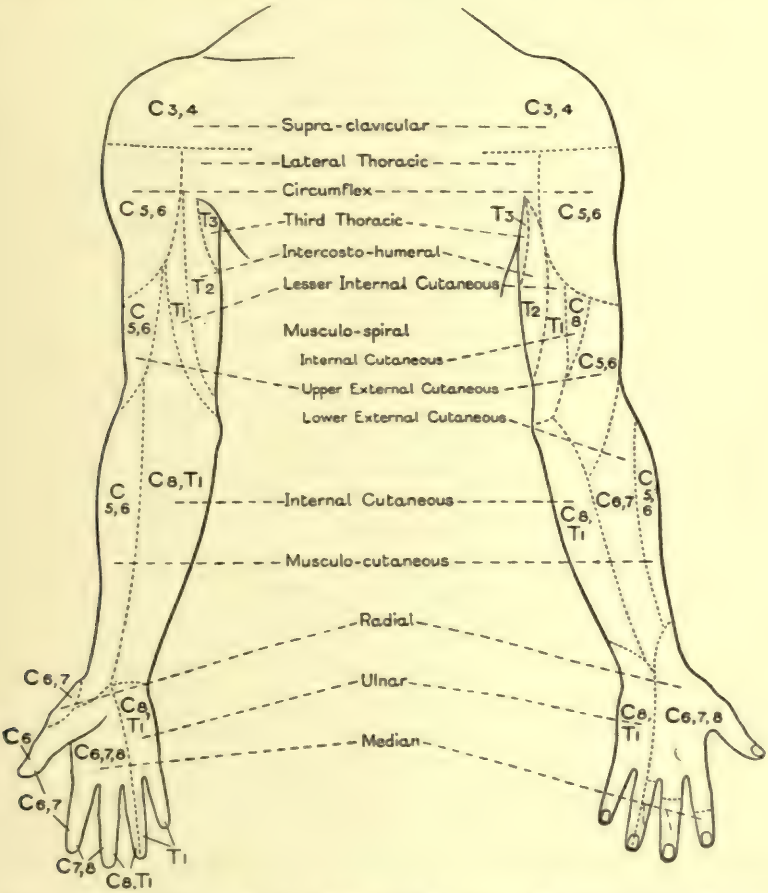


Fig. 9.—Innervation of the skin of the upper limb. All these areas of distribution are the *maximum* areas.

The anterior nerves, derived from anterior trunks of the component nerves, through the outer and inner cords, comprise the musculo-cutaneous, median, ulnar, internal cutaneous, and lesser internal cutaneous nerves—destined for the innervation of the *front* of the arm, forearm, and hand.

The posterior trunk is the musculo-spiral, which arises from the posterior trunks of the last four cervical nerves, and is distributed to the *back* of the arm, forearm, and hand.

(The notable exception to this statement is the dorsal branch of the ulnar nerve, which is distributed to the back of the hand and fingers.)

(*a*) **Anterior Nerves.**

The **musculo-cutaneous nerve** (Fig. 10) takes origin from the fifth and sixth cervical nerves through the outer cord of the brachial plexus. Incorporated with it is a branch from the seventh cervical nerve, which is destined to supply the coraco-brachialis muscle.

The nerve lies at first, with the outer head of the median, external to the axillary artery. Piercing obliquely the coraco-brachialis muscle (the nerve to which enters the muscle before it is pierced by the nerve), it next lies between the biceps and brachialis anticus. It supplies branches to each head of the biceps and to the brachialis anticus. It becomes superficial above the bend of the elbow, appearing at the outer border of the biceps muscle. Passing through the deep fascia it becomes cutaneous, and at once divides into two branches—anterior and posterior. The **anterior branch** supplies the skin of the front of the forearm from the elbow to the wrist, including the upper part of the ball of the thumb. The **posterior branch** supplies the skin of the back of the forearm on the outer side, in the upper two-thirds. The musculo-cutaneous often communicates with the median nerve in the arm beneath the biceps (Fig. 9). This communication may be from either nerve to the other. In some cases a branch from the musculo-cutaneous is carried down in the median to separate in the lower part of the arm as a nerve to the brachialis anticus. In other cases a branch from the median joins the musculo-cutaneous after the muscular branches have arisen from the latter nerve.

The Median Nerve (Fig. 11) takes origin by two heads, an **outer head** derived from the sixth and seventh cervical nerves through the outer cord, and an **inner head** derived from the eighth cervical and first thoracic nerves through the inner cord. The outer head is placed external to the axillary artery; the inner head crosses over the vessel obliquely. Thus formed, the nerve passes down through the upper arm in close relation to the brachial artery. In the upper half of the arm it is external to the artery. In the lower half it crosses over the artery obliquely, so as to be ultimately on its inner side.

It proceeds straight down the middle of the forearm, lying deeply in its whole course. It first passes between the two heads of the pronator radii teres, separated at this stage from the ulnar artery by the deep head of the muscle. Thereafter it proceeds downwards between the flexor

sublimis digitorum and the deep muscles of the forearm to the wrist. In the lower fourth of the forearm the nerve is situated immediately

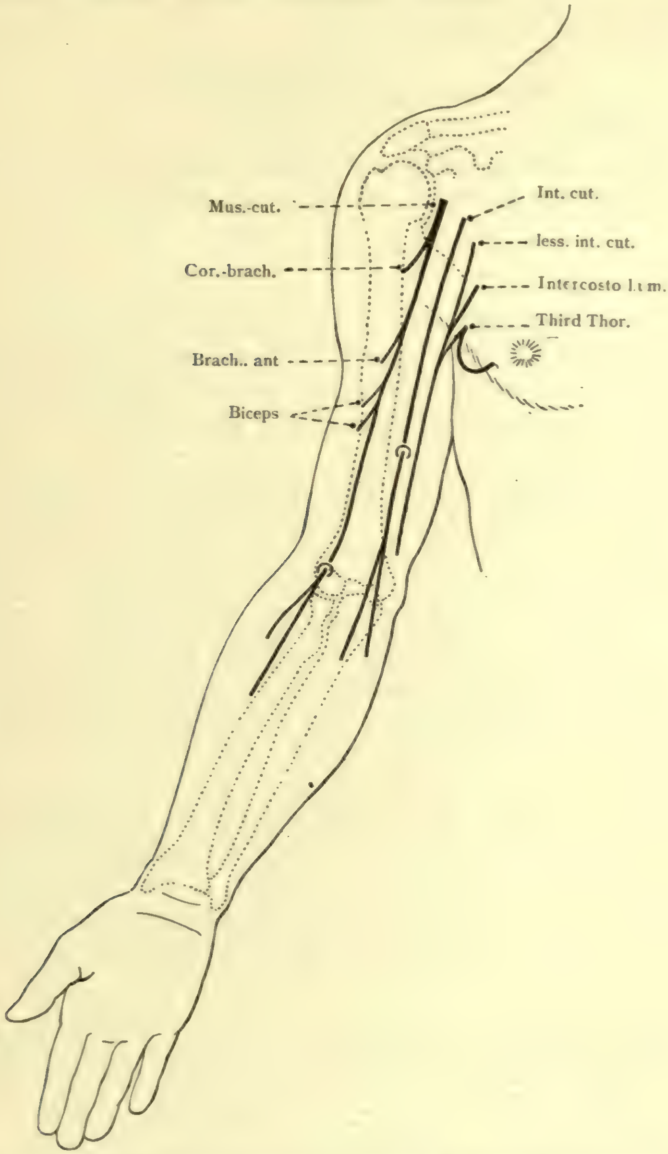


Fig. 10.—Distribution of musculo-cutaneous, internal cutaneous, and intercosto-humeral nerves.

behind the tendon of the palmaris longus muscle, external to the tendons of the flexor sublimis digitorum.

In the forearm it is accompanied by an artery of variable size—the

comes nervi mediani. At the wrist it passes beneath the anterior annular ligament. Reaching the palm of the hand it separates into its terminal branches for the supply of the skin of the fingers and thumb, and of certain muscles of the thumb.

Branches of the Median Nerve.

A. In the Arm.

The median nerve gives off no branches in the arm (except the occasional communication with the musculo-cutaneous nerve already mentioned).

B. In the Forearm.

(1) **Muscular Branches.** The median nerve supplies in the upper part of the forearm the following muscles : Pronator radii teres, flexor carpi radialis, palmaris longus, and flexor sublimis digitorum. A second branch to the flexor sublimis digitorum is given off in the middle third of the forearm (Fig. 11).

Anterior Interosseous Nerve. This nerve arises from the median in the upper third of the forearm, and courses downwards on the interosseous membrane between the flexor longus pollicis and flexor profundus digitorum, accompanied by the anterior interosseous artery. It supplies these muscles, and terminates by entering the posterior surface of the pronator quadratus. It also supplies twigs to the wrist joint.

(2) A **Palmar Cutaneous Branch** arises in the lower third of the forearm and, piercing the fascia above the anterior annular ligament, supplies the skin of the palm of the hand.

(3) A contribution from the ulnar to the median nerve is rarely given off in the forearm. It usually occurs about four inches below the internal condyle, and is said to be composed of fibres from the ulnar to the median nerve, reinforcing the branches of the latter nerve to the parts of the flexor sublimis digitorum, which are associated with the tendons to the third, fourth, and fifth fingers.

C. In the Hand.

(1) **Muscular Branch.** Immediately below the lower border of the anterior annular ligament a short muscular trunk is given off, which is directed outwards superficially to the muscles of the thumb. It supplies the abductor, opponens, and flexor brevis pollicis.

(2) **Cutaneous Branches.** The terminal branches of the nerve are five cutaneous trunks, which pass downwards between the palmar arch and the long flexor tendons to supply (1) and (2) each side of the thumb, (3) the radial side of the index finger and the first lumbrical muscle, (4) the adjacent sides of the index and middle fingers and the second

lumbrical muscle, and (5) the adjacent sides of the middle and ring fingers (Fig. 9).

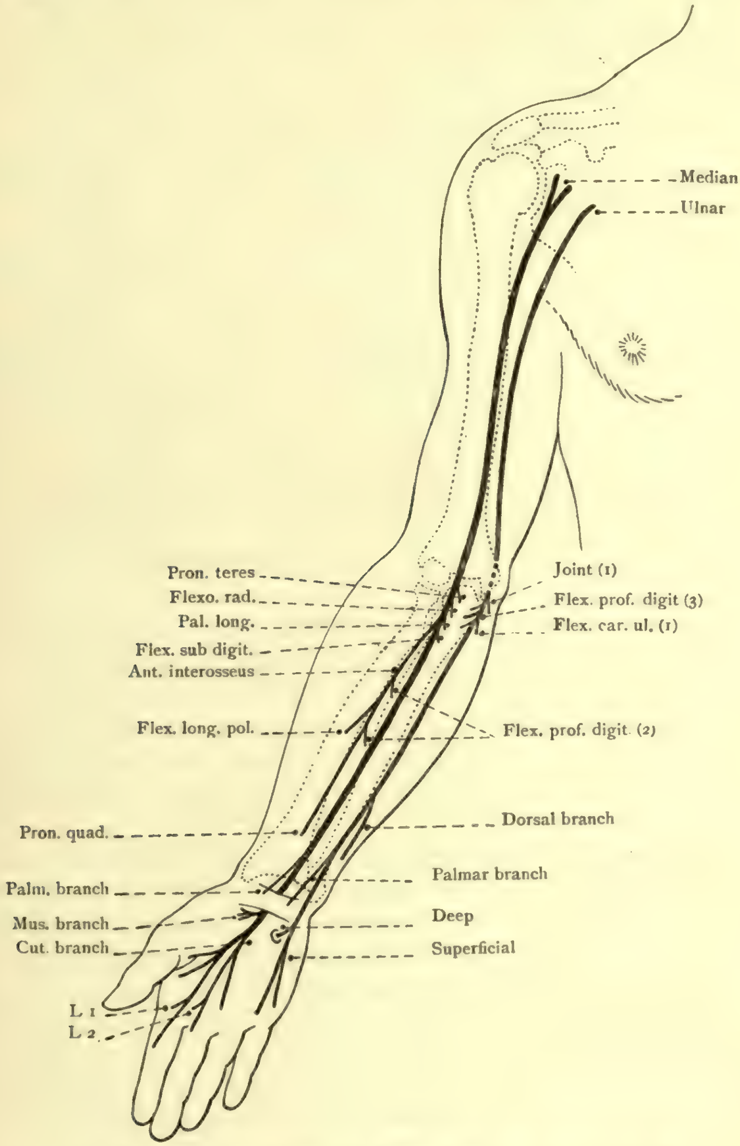


FIG. 11.—Distribution of the median and ulnar nerves.

The cutaneous branches to the index, middle, and ring fingers supply branches which are distributed also to the dorsal aspects of these fingers (Fig. 9).

The **Ulnar Nerve** (Fig. 7) takes origin through the inner cord of the plexus, from the eighth cervical and first thoracic nerves. (It occasionally receives an additional root from the seventh nerve through the outer cord.)

In the axilla it lies on the inner side of the axillary artery, with the other nerves derived from the inner cord.

In the arm the nerve courses downwards at first on the inner side of the brachial vessels. At the middle of the arm it recedes from the artery, and passing over the edge of the internal intermuscular septum, it continues its course behind the septum and in front of the triceps muscle to the elbow. After passing behind the internal condyle of the humerus, where it is to be felt as 'the funny bone', it enters the forearm between the two heads of the flexor carpi ulnaris. In the forearm the nerve passes down on its inner side between the flexor carpi ulnaris and flexor profundus digitorum to the wrist. It joins the ulnar artery in the middle third of its course, and continues onwards on its inner side.

At the wrist, just above the anterior annular ligament, the ulnar nerve and artery pierce the deep fascia, and lie on the anterior annular ligament external to the pisiform bone. They are protected in this situation by a strong band of fascia, which passes from the pisiform bone to the annular ligament.

The nerve divides below the ligament into its terminal branches—superficial and deep—for the supply of the skin and muscles of the hand.

The ulnar nerve gives off no branches in the arm.

At the elbow it supplies an articular branch to the elbow-joint.

In the Forearm (Fig. 11). Just below the elbow **two muscular branches** arise to supply the flexor carpi ulnaris and the inner half of the flexor profundus digitorum muscles.

Two cutaneous branches arise in the forearm.

The **dorsal branch** is given off in the middle third, and passing downwards and backwards behind the flexor carpi ulnaris, it becomes cutaneous in the lower third of the back of the forearm. Passing over the posterior annular ligament the nerve is distributed on the back of the hand and fingers, supplying the back of the little finger in its whole length, and the inner half of the ring finger (Fig. 9).

It supplies in some cases the whole of the back of the ring finger. It communicates with the radial nerve on the back of the hand.

The palmar branch is a minute filament which arises from the ulnar nerve in the lower third of the forearm. It supplies the palm of the hand after passing through the deep fascia and over the anterior annular ligament. It communicates with the palmar branch of the median nerve.

The Ulnar Nerve in the Hand. As already stated, the ulnar nerve divides in the palm into its terminal branches, superficial and deep.

The **superficial branch** supplies twigs to the palmaris brevis muscle and to the skin of the inner part of the palm, and ends by dividing into two digital branches, inner and outer, supplying respectively the inner side of the little finger and the adjacent sides of the little and ring fingers (Fig. 9).

The **deep branch** passes through the origins of the muscles of the little finger, and is situated along with the deep palmar arch upon the interosseous muscles. It supplies the following muscles: the inner two lumbrical muscles, the abductor, opponens, and flexor brevis minimi digiti, all the palmar and dorsal interosseous muscles, the adductor pollicis, and interosseus primus volaris (Henle).

The dorsal branch of the ulnar nerve has been referred to already as an anomalous nerve. Here is a nerve, derived from a combination of **anterior** trunks and formed from both eighth cervical and first thoracic nerves, giving off a large branch for the skin of the back of the hand and fingers. Possibly the nerve represents the posterior trunk of the first thoracic nerve, which instead of separating like the others in the axilla is carried down to the forearm, incorporated with the ulnar nerve.

The **Internal Cutaneous Nerve** (Fig. 7) is also derived from the eighth cervical and first thoracic nerves through the inner cord of the plexus. It lies at first on the inner side of the axillary artery, with the ulnar nerve and the inner head of the median nerve. In the upper half of the arm the nerve is anterior to the brachial artery. At the middle of the arm on the inner side there is a perforation in the deep fascia through which the basilic vein passes to join the brachial veins, and out of which the internal cutaneous nerve emerges to become cutaneous. The nerve supplies twigs to the skin of the arm, and above the elbow divides into anterior and internal branches, for the forearm. The anterior branch supplies the skin of the front of the forearm down to the wrist. The internal branch supplies the skin of the back of the forearm on the inner side in the upper two-thirds (Figs. 9 and 10).

The **Lesser Internal Cutaneous Nerve** (Fig. 7) can be traced through the inner cord of the brachial plexus to the first thoracic nerve. It becomes superficial as a rule at the posterior axillary fold, where it joins and becomes more or less incorporated with the intercosto-humeral nerve. In some cases it joins the intercosto-humeral nerve in the axillary space. The intercosto-humeral nerve is also joined by the posterior trunk of the lateral branch of the third intercostal nerve, so that a strip of skin from the axilla to a point midway between the internal condyle of the humerus and the olecranon process is innervated by the first three thoracic nerves (Figs. 9 and 10).

The **Musculo-spiral Nerve** (Fig. 7) is derived from the posterior trunks of the anterior primary divisions of the last four cervical nerves. (In

some cases it receives a minute filament from the back of the first thoracic nerve.) It forms the continuation of the posterior cord of the plexus into the arm, and is distributed to the back of the arm, forearm, and hand.

The nerve lies at first behind the axillary artery. Proceeding to the arm it is placed in the upper third on the inner side of the humerus and behind the brachial artery. In the middle third it winds round the back of the bone in the spiral groove between the triceps and the humerus, accompanied by the superior profunda artery. In the lower third of the arm it is external to the humerus. Piercing the external intermuscular septum, it passes downwards, lying deeply between the brachio-radialis and brachialis anticus muscles. It terminates in front of the external condyle of the humerus by dividing into the radial and posterior interosseous nerves (Fig. 12).

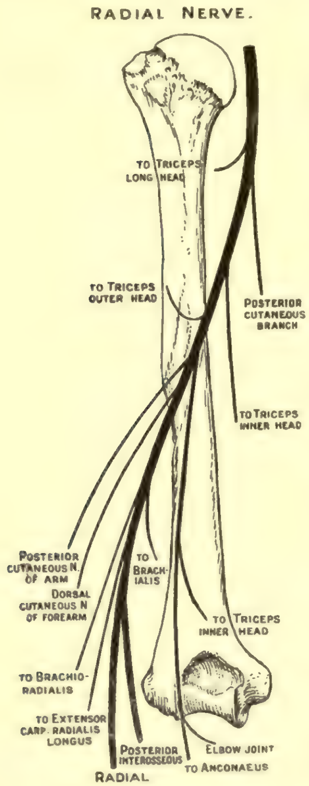


FIG. 12.—Scheme of the musculo-spiral nerve.

The collateral branches of the musculo-spiral nerve are in three sets :

(*a*) Three branches arising on the inner side of the arm :

(1) An **internal cutaneous** branch, distributed to the skin of the arm behind the area supplied by the intercosto-humeral nerve (Fig. 9).

(2) A muscular branch to the **long head of the triceps ;** and

(3) A muscular branch to the **inner head of the triceps.** This nerve accompanies the ulnar nerve in part of its course, and is known as the **ulnar collateral** (Krause).

(*b*) Three series of nerves arising on the back of the arm, while the nerve occupies the spiral groove :

(1) A muscular branch to the **outer head of the triceps.**

(2) A muscular branch to the **inner head of the triceps** (and **anconeus**), which also supplies the elbow-joint ; and

(3) The **external cutaneous branches.**

These are two in number : **superior,** smaller, supplying the skin over the lower half of the back of the arm, and the back of the elbow-joint ; and **inferior,** larger, supplying the skin of the back of the arm in its lower third and the skin of the back of the forearm in its upper two-thirds (Fig. 9).

(*c*) Three muscular branches arise on the outer side of the arm—for the **brachialis anticus, brachio-radialis,** and **extensor carpi radialis longior** (Fig. 12).

The nerve to the brachialis anticus muscle is not always present. The main nerve to the muscle is derived from the musculo-cutaneous nerve. It is well known that a frequent fusion of the brachio-radialis

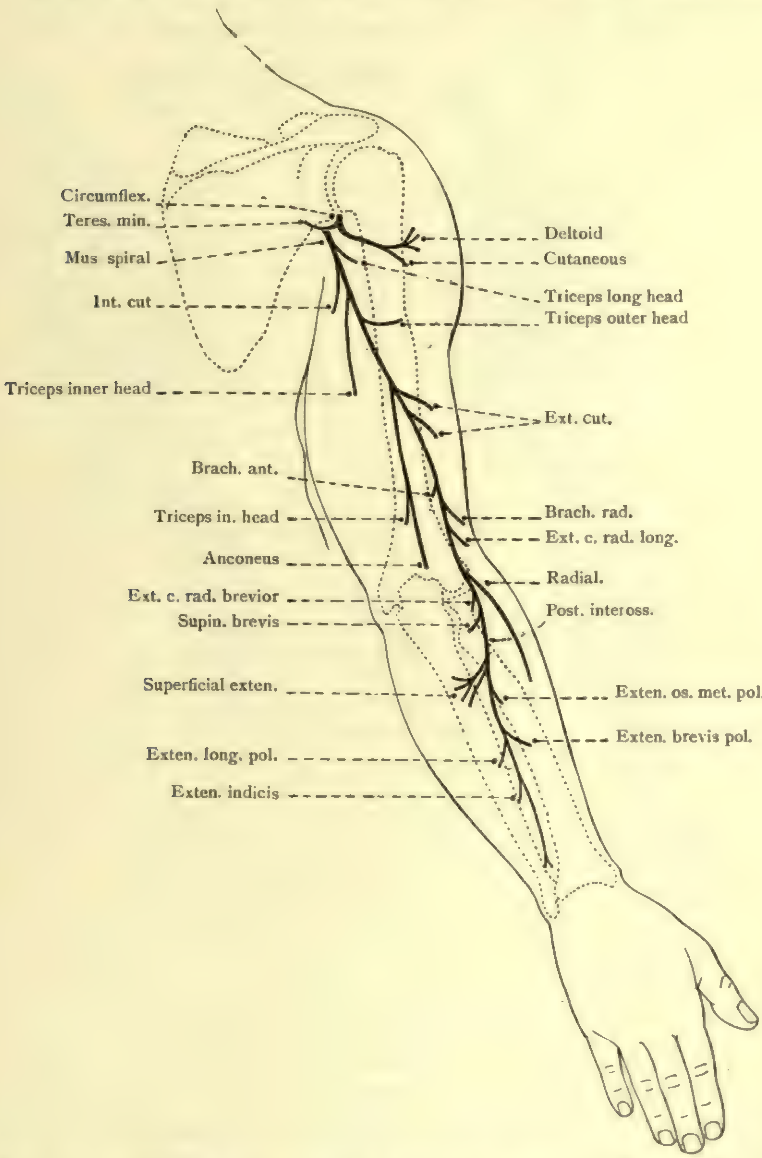


FIG. 13.—Scheme of distribution of branches of musculo-spiral nerve.

and brachialis anticus takes place over the musculo-spiral nerve in this part of its course. It may be that the nerve in question is supplied to fibres of the brachio-radialis which have been incorporated with the brachialis anticus.

Terminal Branches of the Musculo-Spiral Nerve.

The **Radial Nerve** proceeds down the front of the forearm on the outer side under cover of the brachio-radialis muscle. At the junction of the upper and middle thirds of the forearm it meets with the radial artery,

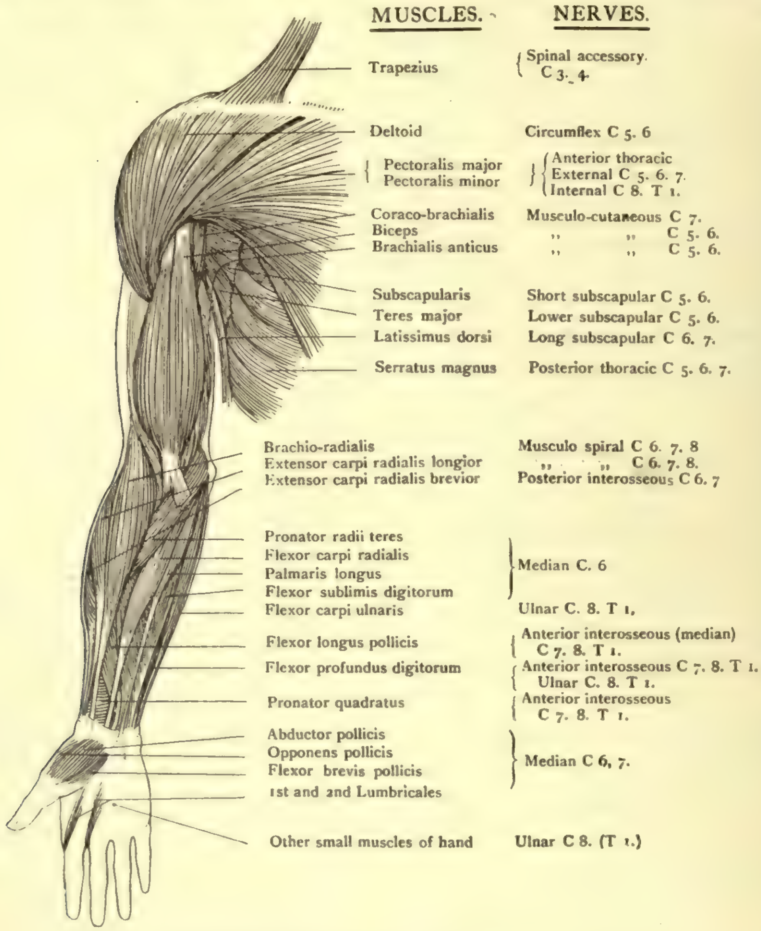


Fig. 14.—Innervation of the muscles of the upper limb. Front of the limb.

which it accompanies—lying on the outer side of the artery—in the middle third. At the junction of the middle and lower thirds of the forearm the nerve is directed obliquely downwards and backwards beneath the tendon of the brachio-radialis, and becomes cutaneous on the back of the forearm.

The radial is a purely cutaneous nerve. It is distributed to the back of the lower third of the forearm and the back of the hand and fingers in

a somewhat variable way. It divides into branches, which as a rule innervate two-thirds of the back of the hand on the outer side, and send branches over the outer part of the ball of the thumb. It supplies the whole dorsum of the thumb, the skin over the proximal phalanx of

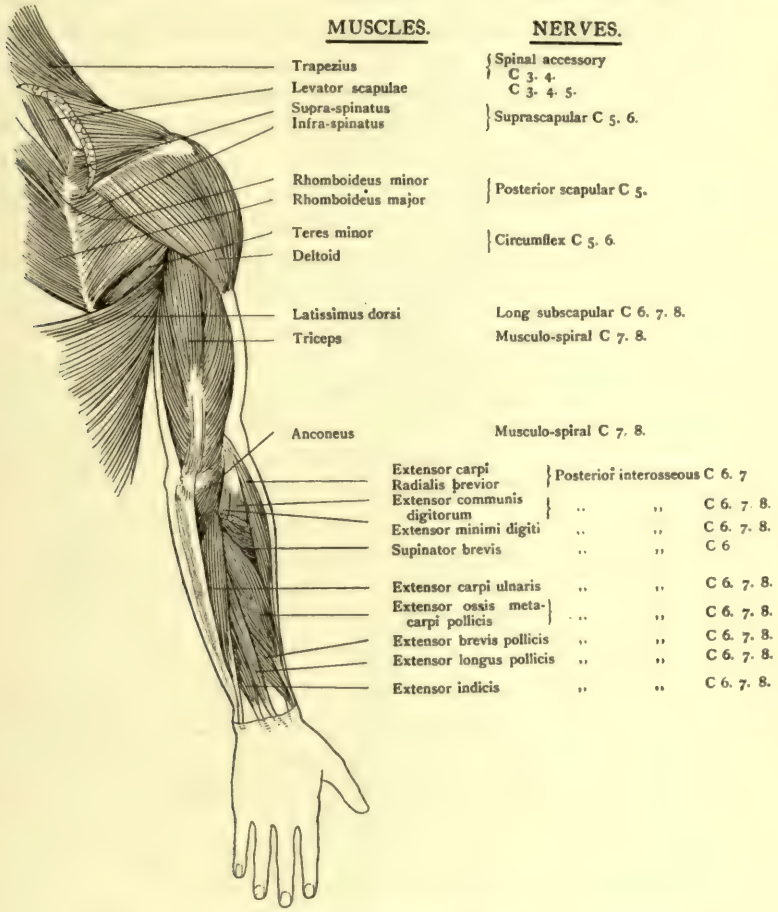


FIG. 15.—Innervation of the muscles of the upper limb. Back of the limb.

the fore finger and part of the proximal phalanx of the middle finger (Fig. 9). The areas of skin between the proximal phalanges of the middle and ring fingers may be supplied by the radial or by the dorsal branch of the ulnar nerve.

In many instances the area supplied is less than that indicated. On the other hand, cases are recorded in which the radial nerve supplies the whole of the back of the hand and fingers.

The **Posterior Interosseous Nerve** is chiefly muscular in distribution.

Proceeding downwards on the front of the upper arm of the forearm on the outer side, under cover of the brachio-radialis muscle, the nerve pierces the supinator brevis muscle, and, sweeping round the shaft of the radius, appears in the upper third of the back of the forearm.

Occupying on the back of the forearm at first a position beneath the origins of the superficial extensor muscles of the forearm, it lies successively on the supinator brevis and extensor ossis metacarpi pollicis. It then passes beneath the extensor longus pollicis, and continues its course on the interosseous membrane. It finally ends by passing as a minute nerve over the back of the lower end of the radius to supply the radio-carpal and intercarpal joints. In the middle third of the back of the forearm the nerve is accompanied by the posterior interosseous artery.

The collateral branches of the posterior interosseous nerve are in two sets. Before the nerve pierces the supinator brevis it supplies branches to two muscles—**extensor carpi radialis brevior** and **supinator brevis.** Immediately after appearing on the back of the forearm the nerve supplies a bundle of branches for the **extensor longus digitorum, extensor minimi digiti,** and **extensor carpi ulnaris.** Proceeding onwards, the nerve supplies branches to the **extensor ossis metacarpi pollicis, extensor longus pollicis, extensor brevis pollicis,** and **extensor indicis.**

Cases are on record in which the posterior interosseous nerve has given rise to a cutaneous branch for the skin of the adjacent sides of the fore and middle fingers.

The Lumbo-sacral Plexus.

In many animals the lumbo-sacral plexus for the formation of nerves of distribution to the lower limb is separate and distinct from the pudendal plexus, destined for the perineum and caudal region. In man, however, there is no distinct differentiation, and the nerves of the lumbo-sacral and pudendal plexuses overlap at their origins.

For the purposes of convenience and lucidity, however, it is best to describe the two plexuses separately.

The lumbo-sacral plexus is primarily the plexus for the provision of nerves of distribution to the lower limb. While most of the nerves entering into its composition are distributed wholly to the limb, those at the cephalic and caudal ends of the series (first lumbar and second and third sacral) are distributed to the trunk as well.

The plexus is formed by the anterior primary divisions of all the lumbar nerves, and of the first three sacral nerves. It is separated by the sacro-iliac articulation into two parts, lumbar and sacral. The nerve of junction, entering into the formation of both portions, is the fourth lumbar nerve; in mammals, as a general rule, the penultimate lumbar nerve. This nerve is sometimes called the *nervus furcalis* (Fig. 16).

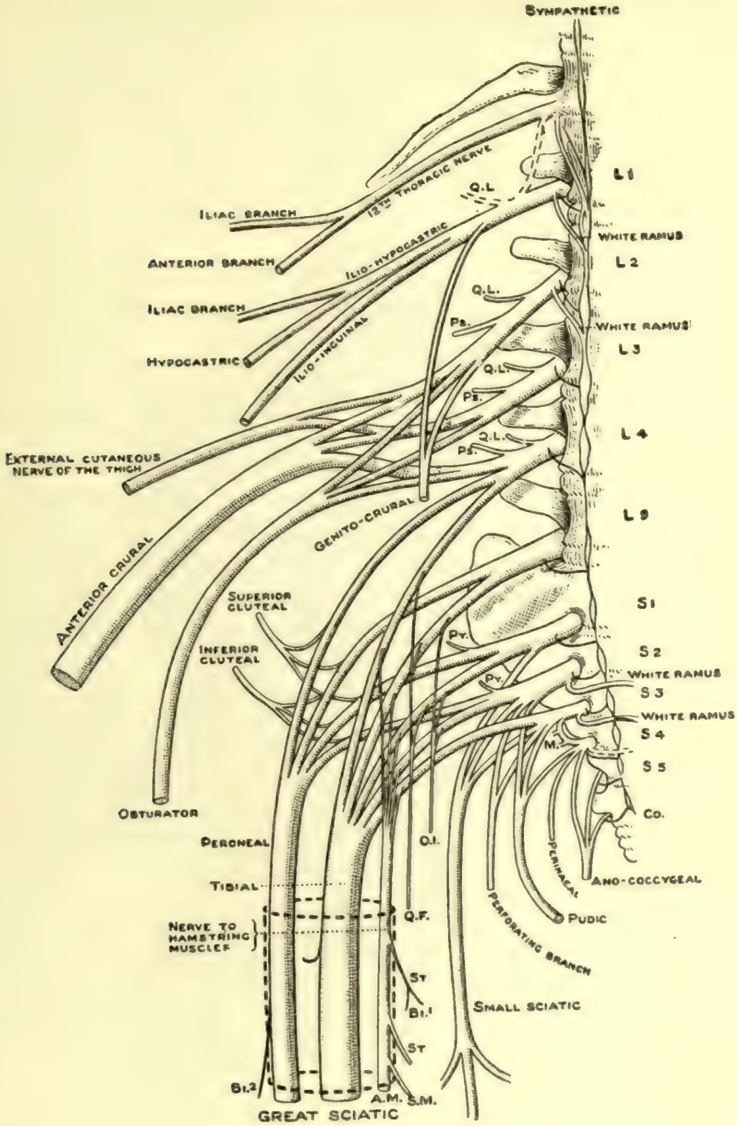


FIG. 16.—The lumbo-sacral plexus.

LUMBAR PART OF THE PLEXUS.

The **lumbar** part of the plexus is formed in the substance of the psoas muscle, from which its nerves of distribution emerge on the posterior abdominal wall (Fig. 17).

The nerves which enter into its formation are the anterior primary

divisions of the first three lumbar nerves and a part of the fourth, with sometimes a communication from the twelfth thoracic nerve.

The nerves of the plexus are collateral and terminal. The **collateral branches** are given off from the separate spinal nerves to the following muscles:

Quadratus lumborum	(L 1, 2, 3 (4))
Psoas magnus	(L (1), 2, 3 (4))
Psoas parvus	(D 12 and L 1)

The **terminal branches** of distribution are the following:

Ilio-hypogastric	(L 1)
Ilio-inguinal	(L 1)
Genito-crural	(L 1, 2)
External cutaneous	(L 2, 3)
Obturator	(L 2, 3, 4)
Anterior crural	(L 2, 3, 4)

The **ilio-hypogastric** and **ilio-inguinal** nerves, derived from the first lumbar nerve with an occasional contribution from the twelfth thoracic, resemble in their course and distribution the lower thoracic nerves.

The **ilio-hypogastric nerve** emerges from the outer border of the psoas magnus muscle, and traverses the posterior abdominal wall, lying on the quadratus lumborum muscle. Piercing the transversalis abdominis muscle, it proceeds downwards and forwards between it and the obliquus internus to a point in front of the anterior superior spine. Here it pierces the obliquus internus muscle, and proceeds onwards under cover of the aponeurosis of the obliquus externus. Piercing this about one and a half inches from the crest of the pubis, it ends by supplying the skin of the lower part of the abdominal wall. This nerve supplies muscular branches to the muscles between which it lies, and gives off a lateral (iliac) branch of small size, which passes over the iliac crest to supply a small area of the skin of the buttock (Figs. 17 and 18).

The **ilio-inguinal nerve** has a somewhat similar course and distribution, but it gives off no lateral branch. Arising with the ilio-hypogastric nerve, it has a similar course, at a lower level, as far as the anterior abdominal wall. Here it pierces the internal oblique muscle below and in front of the ilio-hypogastric nerve, and proceeds downwards and forwards between the aponeurosis of the obliquus externus and the cremaster muscle. It becomes cutaneous by passing through the external abdominal ring, and is finally distributed to the skin over the pubis, to the root of the penis, the base of the scrotum, and the inner part of Scarpa's triangle (Fig. 18).

The remaining nerves belonging to the lumbar portion of the plexus are four in number:

Genito-crural and **obturator**, which are anterior or ventral in origin

and distribution, and **external cutaneous** and **anterior crural**, which are posterior or dorsal.

The **genito-crural nerve** is formed in the substance of the psoas muscle by the union of two slender roots from the front of the first and second lumbar nerves. Piercing the psoas muscle, the nerve passes down to the groin, where it divides into **crural** and **genital** branches (Fig. 17).

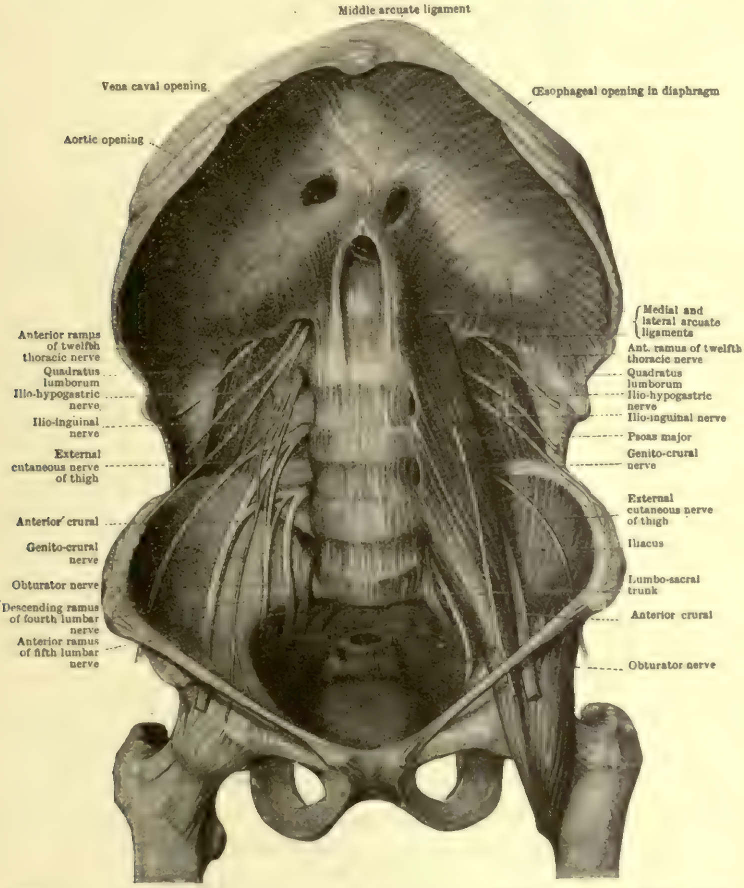


FIG. 17.—The muscles and nerves on the posterior abdominal wall.

The **crural** branch passes beneath Poupart's ligament on the outer side of the femoral artery, to which it supplies small twigs, and piercing the fascia lata external to the saphenous opening, it supplies the skin over the outer part of Scarpa's triangle.

The **genital** branch passes obliquely downwards and forwards into the inguinal canal, and supplies the cremaster muscle.

The **external cutaneous nerve** arises by two roots from the back of the trunks of the second and third lumbar nerves (Fig. 16). It is a consider

able nerve, which pierces the outer border of the psoas magnus muscle about its middle. Sweeping across the iliacus muscle, it passes beneath

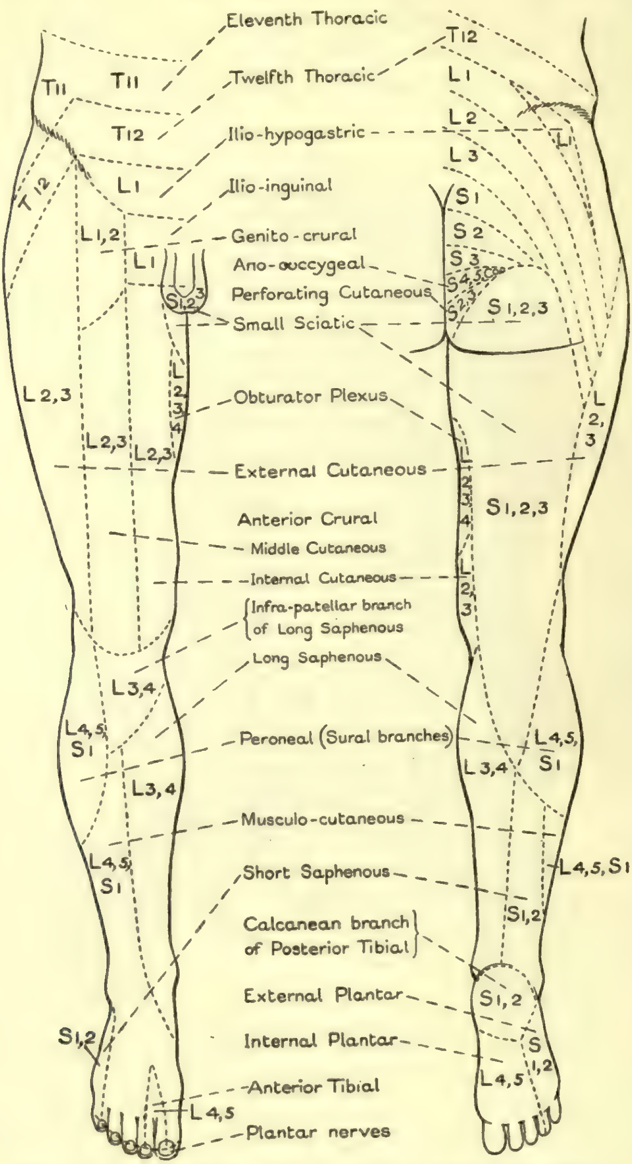


FIG. 18.—Innervation of the muscles of the lower limb.

Poupart's ligament just below the anterior superior iliac spine, and passes over, under, or through the sartorius muscle, near its origin. It occupies a sheath of fascia lata for four or five inches on the outer side of the thigh

in its upper fourth before finally becoming cutaneous. It divides into **anterior** and **posterior** trunks for the supply of the skin on the front and outer side of the thigh in its whole extent (Fig. 18).

The **Obturator** and **Anterior Crural** nerves are closely associated at their origins, and are distinctly comparable to nerves of the brachial plexus, arising respectively from anterior and posterior cords. The main parts of the anterior primary divisions of the second and third lumbar nerves, and the part of the fourth engaged in the formation of the lumbar part of the plexus, subdivide in the substance of the psoas magnus into anterior or ventral and posterior or dorsal branches. The anterior trunks of the nerves combine to form the obturator. The posterior trunks give rise to the anterior crural nerve (Fig. 16).

They correspond in a similar way in their distribution. The obturator supplies the adductor muscles and the skin of the inner side of the thigh—parts which are primitively ventral in position. The anterior crural supplies muscles and skin on the front of the limb—parts which are primitively dorsal in position.

The **Obturator Nerve** passes vertically downwards in the substance of the psoas magnus, from the inner border of which it emerges at the pelvic brim. Passing external to the internal iliac vessels and the ureter, and lying in the extra-peritoneal tissue, accompanied by the obturator artery it enters the thigh through the obturator foramen. In the foramen it divides into two branches—superficial and deep (Fig. 19). The **superficial branch** passes in front of the obturator externus and adductor brevis muscles, and behind the pectineus and adductor longus. It finally subdivides at the inner border of the adductor longus into its terminal branches, of which one supplies the femoral artery and the other, passing between the sartorius and gracilis, ends by supplying the skin of the inner side of the thigh in its middle third. This branch joins the **obturator plexus,** formed by its union with twigs from the internal cutaneous and internal saphenous branches of the anterior crural nerve (Fig. 18).

The **collateral branches** of the superficial part of the obturator nerve supply the hip-joint, the **adductor longus,** and **gracilis,** and sometimes the **pectineus** and the **adductor brevis** muscles.

The **deep part of the obturator nerve** enters the thigh after piercing the obturator externus muscle. It passes down the thigh between the adductor brevis and adductor magnus muscle, and after piercing the latter muscle it applies itself to the popliteal artery, and ends as an articular (geniculate) branch for the knee-joint.

Its **collateral branches** are the nerve to the **obturator externus** muscle (which arises before the nerve pierces the muscle), and muscular branches to the **adductor magnus** and **adductor brevis** (if this muscle is not innervated by the superficial part of the nerve) (Fig. 20).

The **Anterior Crural Nerve** (Fig. 16) is the largest nerve of this series. Formed in the substance of the psoas magnus by the union of the posterior trunks of the anterior primary divisions of the second, third, and fourth lumbar nerves, it extends obliquely downwards and outwards through the muscle to its outer border, from which it emerges in the false pelvis in a groove between the psoas and iliacus muscles. Passing into the thigh

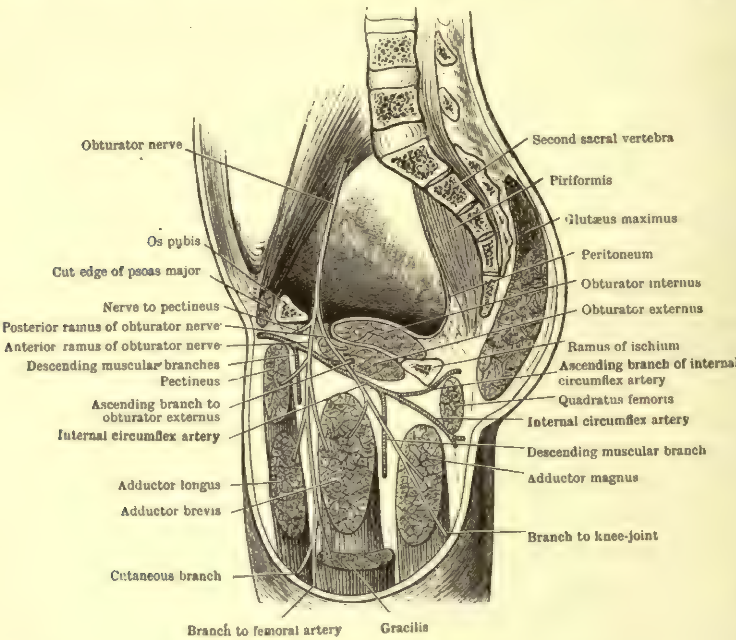


FIG. 19.—Scheme of the distribution of the obturator nerve.

beneath Poupart's ligament it divides in Scarpa's triangle into a sheaf of branches, for the supply of the skin and muscles of the lower limb. In the thigh it lies external to the femoral vessels, and outside the femoral sheath. The external circumflex artery passes outwards among the branches of the nerve near their origins.

The branches of the anterior crural nerve (Fig. 21) are articular, muscular, and cutaneous. **Articular branches** are supplied to the hip-joint directly, and through the nerves to the vastus internus muscle, to the knee-joint. **Muscular branches** supply the iliacus, sartorius, pectineus, and quadriceps extensor—rectus femoris, vastus externus, vastus internus, crureus, and subcrureus. The nerve to the pectineus passes inwards behind the femoral vessels. It is usually the only nerve to this muscle. Occasionally a small nerve enters the muscle from behind—a branch of the superficial part of the obturator nerve. The occurrence

of this nerve is associated with the inclusion in the pectineus muscle of a part of the adductor muscular mass.

The **cutaneous branches** are the following (Figs. 18 and 21):

(*a*) **Two middle cutaneous nerves.** These pierce the deep fascia in the upper third of the front of the thigh, after passing over or through the sartorius muscle. They innervate the skin of the front of the thigh down to the knee.

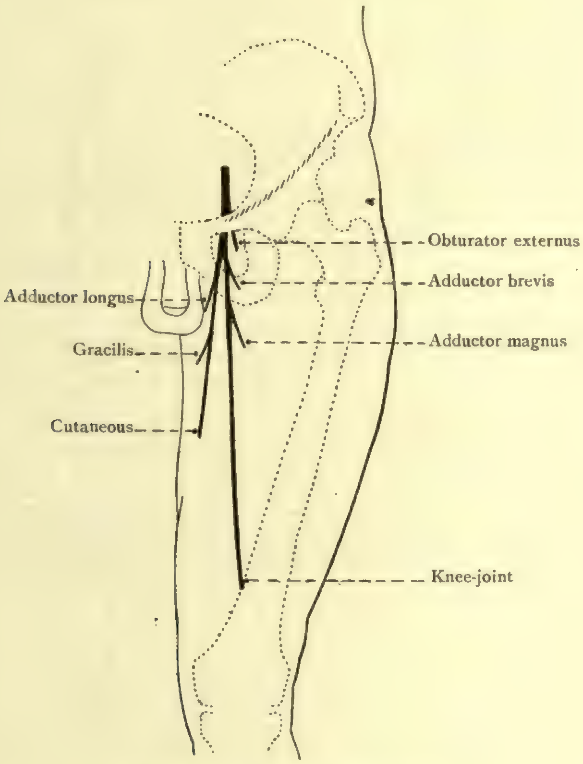


FIG. 20.—Obturator nerve.

(*b*) There are usually **three internal cutaneous nerves**—upper, middle, and lower. The upper branch pierces the deep fascia near the apex of Scarpa's triangle, and supplies the skin of the middle third of the thigh on the front and inner side. This nerve sends twigs to the *obturator plexus*. The middle branch supplies the skin of the lower third of the thigh, while the lower branch, becoming superficial a short distance above the knee, supplies the skin of the inner side of the knee and leg.

(*c*) The **internal or long saphenous nerve** may be regarded as the terminal branch of the anterior crural nerve. It courses downwards through Scarpa's triangle, lying external to the femoral vessels. It crosses the vessels in Hunter's canal, where it supplies a communication to the

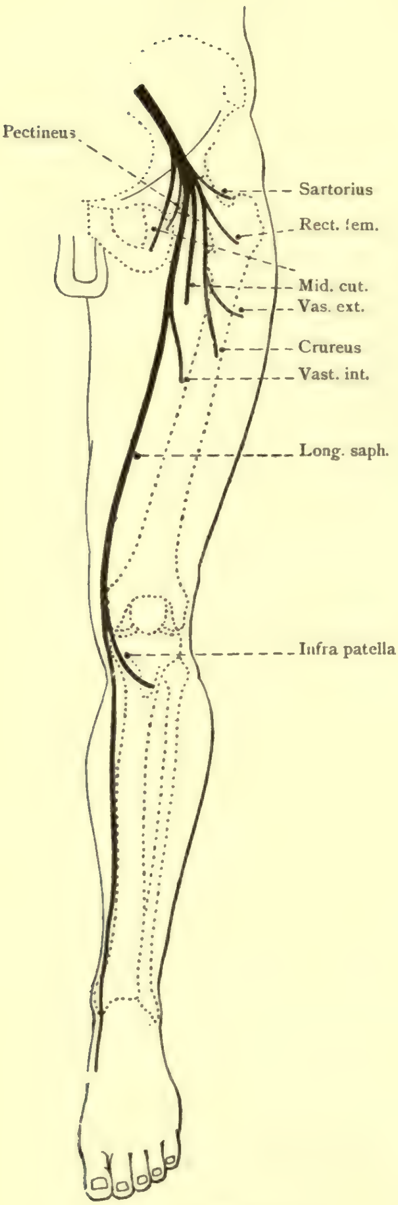


FIG. 21.—Distribution of anterior crural nerve.

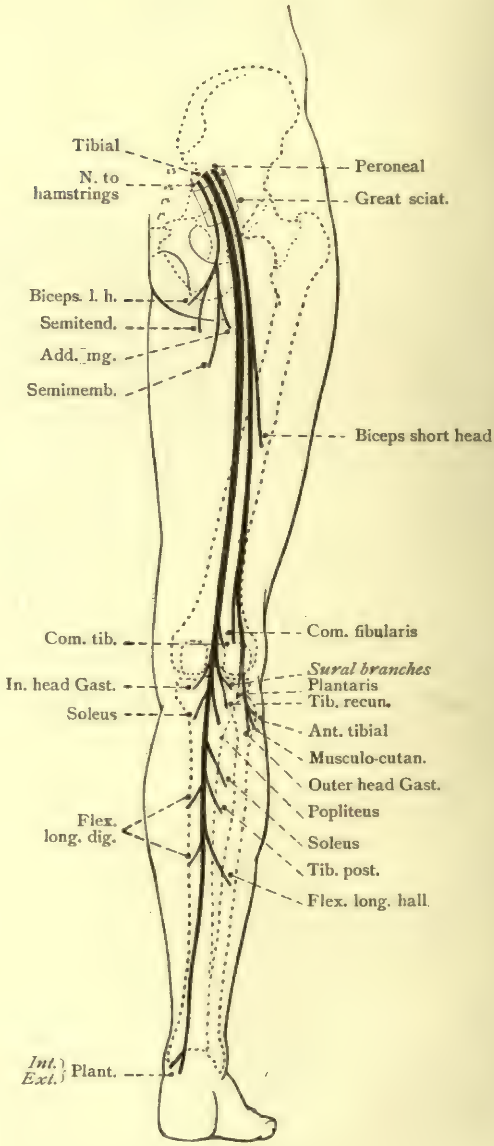


FIG. 22.—Great sciatic nerve.

obturator plexus, and passing between the sartorius and gracilis muscles in company with the superficial branch of the anastomatic artery, it becomes cutaneous at the inner side of the knee. It passes down the inner side of the leg in company with the internal saphenous vein, and going over the internal malleolus, terminates at the middle of the inner border of the foot.

The long saphenous nerve itself supplies the skin of the inner side of the leg in its whole extent, as well as the skin over the internal malleolus, and the inner side of the foot as far as the middle of the inner border (Fig. 18).

Before becoming cutaneous the nerve gives off a **patellar branch** which pierces the sartorius muscle at the inner side of the knee, and sweeping over the inner tuberosity of the tibia supplies the skin of the upper part of the leg (Fig. 18).

Patellar Plexus. Communications occur in front of the patella between the cutaneous branches of the external cutaneous, middle and internal cutaneous, and the patellar branch of the internal sapheous nerves.

The so-called **Accessory Obturator Nerve.** This is a nerve which is only occasionally present. It arises in reality from the roots of the anterior crural nerve (L. 3, 4). It passes into the thigh between Poupart's ligament and the pubis. It is usually distributed in the thigh in the form of three branches—one to the hip-joint, one to the pectineus muscle, and one to communicate with the anterior crural nerve. Cases have been seen in which it was much larger, contributing a large cutaneous branch to the inner side of the thigh, which communicates with the obturator plexus.

The Sacral Plexus.

The sacral portion of the plexus for the lower limb is formed by part of the fourth lumbar nerve, the fifth lumbar, and first two sacral, and usually a considerable portion of the third sacral nerve. In a minority of cases the third sacral nerve does not participate.

General Survey (Fig. 16). The contributory part of the fourth lumbar nerve pierces the psoas magnus muscle on its inner side, and joins the anterior primary division of the fifth lumbar nerve to form the so-called lumbo-sacral cord. This cord enters the pelvis in front of the lateral mass of the sacrum, and forms part of a broad band, the **great sciatic nerve,** which is completed by the addition of the anterior primary divisions of the first two and a part of the third sacral nerves. This band is formed in the pelvis in front of the pyriformis muscle. It enters the buttock, where it lies beneath the gluteus maximus, by passing through the great sciatic foramen below the pyriformis muscle. Passing below the edge of the gluteus maximus midway between the great trochanter of the femur

and the ischial tuberosity, it occupies the back of the thigh, covered by the hamstring muscles. It gives off from its inner side in one or two bundles **the nerve to the hamstring muscles,** and divides at a variable point into **the external popliteal** or **peroneal** and the **internal popliteal** or **tibial** nerves.

In a freshly killed animal the nerve can be made out to consist of three essential parts lying side by side and bound together by a delicate connective tissue sheath—peroneal, tibial, and nerve to the hamstrings from without inwards.

Not infrequently the peroneal and tibial nerves are separate from their origin, being separated in the buttock by a slip of the pyriformis, the peroneal nerve dividing the muscle into two parts.

While the nerve to the hamstring muscles has a closer connexion than the peroneal with the tibial trunk, there is no doubt that these three nerves are separate and distinct in origin as in distribution.

The peroneal and tibial nerves separate from one another at a variable point. As already stated they may be separate from their origin, or the great sciatic nerve may divide at any point between the great sacrosciatic foramen and the popliteal space. There is no interchange of fibres between the two nerves in any part of their course.

The **peroneal nerve,** when united with the tibial and the nerve to the hamstring muscles in the great sciatic trunk, can be readily separated and dissected up to its origin from the sacral plexus. The **peroneal nerve** is formed by the union of a series of trunks which come from the fourth and fifth lumbar and the first two sacral nerves. When the second sacral nerve is the last to enter into the formation of the great sciatic trunk the **first** sacral is the lowest in the composition of the peroneal trunk.

Each of the anterior primary divisions concerned, except the last, divides into posterior or dorsal, and anterior or ventral trunks. The posterior or dorsal trunks of the fourth and fifth lumbar and first two sacral nerves unite to form the peroneal nerve, which thus corresponds to the musculo-spiral nerve of the upper limb.

The **tibial nerve** is formed by the union of the anterior or ventral trunks of the anterior primary divisions of the fourth and fifth lumbar, and first two sacral nerves, with the addition of a part of the third sacral nerve. As already mentioned, there may be no contribution from the third sacral nerve. These component trunks lie ventral to the trunks forming the peroneal nerve, and can be traced for a considerable distance in the great sciatic trunk before subdividing and reuniting to form the nerves of distribution associated with the tibial nerve.

The **nerve to the hamstring muscles,** lastly, has similar individuality in regard to its origin. Emerging as one or two bundles of nerves from the inner border of the great sciatic (or tibial) nerve, it forms a distinct trunk on the inner side of the nerve in the buttock. Traced up to the anterior

primary divisions, it is found to take origin from all the nerves concerned in forming the tibial trunk—by roots which lie on the ventral or anterior aspect of the origins of the tibial nerve. These trunks pass down and subdivide and reunite to form the nerves for the supply of the individual muscles.

Distribution of the Nerves of the Sacral Part of the Plexus.

Collateral Branches in the Buttock. There are two series of collateral branches arising in the buttock.

(*a*) **Three Posterior (dorsal) Branches.** (1) **Nerves to the Pyriformis Muscle** are two small branches arising from the dorsal aspect of the first and second sacral nerves, which enter the muscle separately.

(2) The **superior gluteal nerve** arises from the back of the posterior trunks of the fourth and fifth lumbar and the first sacral nerve. It passes through the great sacro-sciatic foramen into the buttock, above the pyriformis muscle, in company with the gluteal artery. It is placed deeply beneath the glutei—maximus and medius—and after supplying the glutei—medius and minimus—it passes forwards to terminate in the tensor fasciæ femoris muscle.

(3) The **inferior gluteal nerve** arises from the back of the posterior trunks of the fifth lumbar and first two sacral nerves. Appearing in the buttock below the pyriformis muscle, it is distributed solely to the gluteus maximus muscle. It gives off in rare cases the nerve to the short head of the biceps muscle.

(*b*) **Two Anterior (ventral) Branches.** (1) The nerve to the **obturator internus** muscle arises from the front of the anterior trunks of the fifth lumbar and first two sacral nerves, or from the first three sacral nerves. Leaving the pelvis through the great sacro-sciatic foramen, it lies on the spine of the ischium in company with the internal pudic vessels and nerve, and passing through the small sacro-sciatic foramen it supplies the obturator internus muscle on its deep surface. It gives off the nerve to the **superior gemellus** muscle.

(2) The nerve to the **quadratus femoris** muscle arises from the front of the anterior trunks of the fourth and fifth lumbar and first sacral nerves. It passes through the buttock, concealed by the great sciatic nerve and by the obturator internus and gemelli muscles. It ends on the deep surface of the quadratus femoris, and supplies the nerve to the **inferior gemellus.**

The Distribution of the Great Sciatic Nerve.

The great sciatic nerve at the lower border of the pyriformis muscle consists of three elements bound together in a delicate fibrous sheath—from without inwards—**peroneal, tibial,** and **nerve to the hamstring** muscles (Fig. 24).

Having predicated that the peroneal and tibial (external and internal popliteal) nerves are entirely distinct in origin, if we turn to their distribution we find a similar distinction. The peroneal nerve has a dorsal distribution—to the muscles and skin of the dorsal aspect of the leg and foot; while the tibial nerve has a ventral distribution—to the back of the leg and the sole of the foot (originally ventral surfaces). The nerve to the hamstrings is not only ventral in origin, but also in distribution.

The **nerve to the hamstring muscles** may or may not be regarded as a collateral branch of the tibial nerve. It supplies branches to the following muscles:

Adductor magnus . . .	(L. 4, 5)
Semimembranosus . . .	(L. 4, 5, S. 1)
Semitendinosus	(L. 5, S. 1, 2)
Biceps (long head) . . .	(S. 1, 2, 3)

The adductor magnus muscle has a double nerve supply, due to its formation from two masses of muscular tissue. Both are ventral—one associated with the adductor group of muscles, supplied by the obturator nerve, the other associated with the hamstring group, supplied by the nerve to the hamstrings. It is noteworthy that the innervation is numerically continuous (L. 3, 4, 5, S. 1).

The Peroneal (External Popliteal) Nerve.

(1) **In the thigh,** while incorporated in the great sciatic nerve, the peroneal nerve gives off only one branch as a rule—the nerve to the short head of the biceps. With this is associated a fine filament for the outer side of the knee-joint (Fig. 22).

This nerve, as already stated, in rare cases is a branch of the inferior gluteal nerve, the nerve to the gluteus maximus muscle.

The short head of the biceps is a separated portion of the gluteus maximus. It is a dorsal muscle, and in Ruminants forms a continuous portion of the gluteus maximus. In man it has become almost completely detached from the gluteus maximus and has become united with the long head of the biceps—a ventral muscle.

(2) In the **popliteal space,** after separating from the great sciatic trunk, the peroneal nerve follows the course of the biceps tendon, and becomes superficial at the outer side of the space. It courses downwards and outwards parallel to that tendon to a point just below the head of the fibula, where it can be felt as a 'funny bone'. It is immediately beneath the fascia lata, and there divides into its three terminal branches —**anterior tibial recurrent, anterior tibial,** and **musculo-cutaneous.**

Collateral Branches (Fig. 18). The peroneal nerve gives off in this part of its course two sets of collateral branches:

(1) **Communicans fibularis,** which passes down the back of the leg

under the deep fascia to unite with the corresponding branch (**communicans tibialis**) from the tibial nerve to form the short or **external saphenous nerve.**

(2) **Sural Branches.** Several branches arise from the peroneal nerve before its final subdivision to supply the skin over the back and outer side of the calf of the leg (Fig. 22).

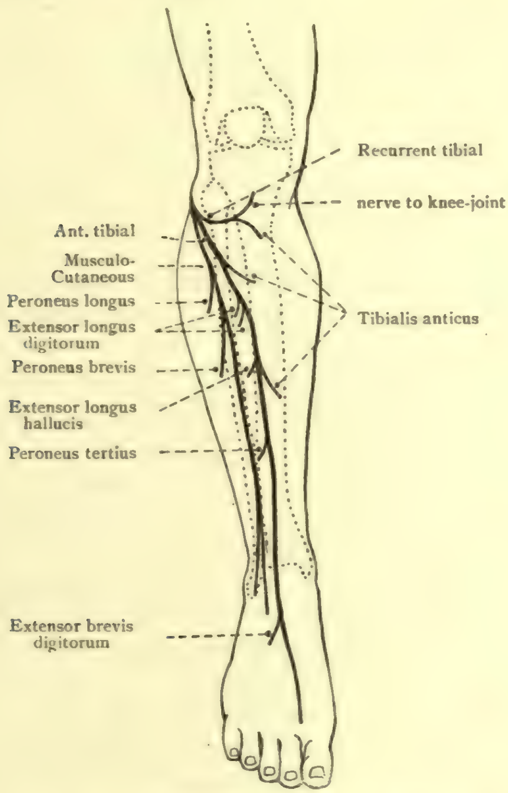


FIG. 23.—Peroneal nerve on the front of leg and dorsum of foot.

The **Terminal Branches** separate from the peroneal nerve below the head of the fibula, and just before their disappearance beneath the origin of the peroneus longus muscle (Fig. 23).

(1) **Anterior Tibial Recurrent Nerve.** This nerve is the highest of the three at their origin. It supplies the knee-joint and the upper fibres of the tibialis anticus.

(2) **Anterior Tibial Nerve.** This nerve is intermediate in position at its origin. Clinging to the fibula it passes downwards and forwards beneath the origins of the peroneus longus and extensor communis digitorum muscles.

On the front of the leg it is deeply placed, lying on the interosseus membrane, between the tibialis anticus and extensor proprius hallucis muscles. At the ankle it passes in front of the lower end of the tibia and is crossed by the tendon of the extensor longus hallucis.

On the dorsum of the foot it divides into its terminal branches, **external** and **internal.** It is accompanied in its course by the anterior tibial and dorsalis pedis arteries.

Collateral Branches (Fig. 23). The anterior tibial nerve supplies the extensor group of muscles on the front of the leg :

Tibialis anticus	(L. 4, 5, S. 1)
Extensor longus hallucis . . .	
Extensor longus digitorum . .	
Peroneus tertius	

Terminal Branches. (1) **External.** On this branch is a distinct pseudo-ganglionic enlargement. It supplies the **extensor brevis digitorum** muscle and the articulations of the tarsus.

(2) **Internal.** This branch passes to the interval between the first and second toes, and supplies a small area of the skin of the dorsum of the foot and the adjacent sides of these toes (Fig. 18).

(3) **Musculo-cutaneous Nerve.** This nerve passes obliquely downwards and forwards, lying at first between the origin of the peroneus longus and the fibula. It then occupies a fibrous sheath in the septum between the extensor and peronei muscles, and pierces the deep fascia below the middle of the leg. It divides into two terminal branches, internal and external, for the supply of the skin of the front of the leg and the dorsum of the foot and toes.

Collateral Branches. Two **muscular branches** are supplied for the **peronei**, **longus** and **brevis**, while the nerve is deeply placed. The nerve for the peroneus longus arises while the nerve lies beneath that muscle. That for the peroneus brevis arises in the upper third of the leg (Fig. 23).

Terminal Branches. These are both cutaneous nerves.

The **internal** branch supplies the skin of the front of the leg in the lower half, and the inner part of the dorsum of the foot. It ends in two branches, one for the supply of the inner side of the foot and great toe, the other for the skin between the second and third toes. The internal branch communicates with the internal saphenous nerve and with the cutaneous branch of the anterior tibial nerve (Fig. 18).

The **external** branch supplies the skin of the front of the leg and the outer side of the dorsum of the foot. It ends by dividing into two branches for the supply of the skin between the third and fourth and fourth and fifth toes. It communicates on the outer side of the foot with the external saphenous nerve.

THE TIBIAL (INTERNAL POPLITEAL) NERVE.

This nerve is ventral in origin and in distribution. It passes through the thigh, popliteal space, and leg, and finally divides at the ankle into

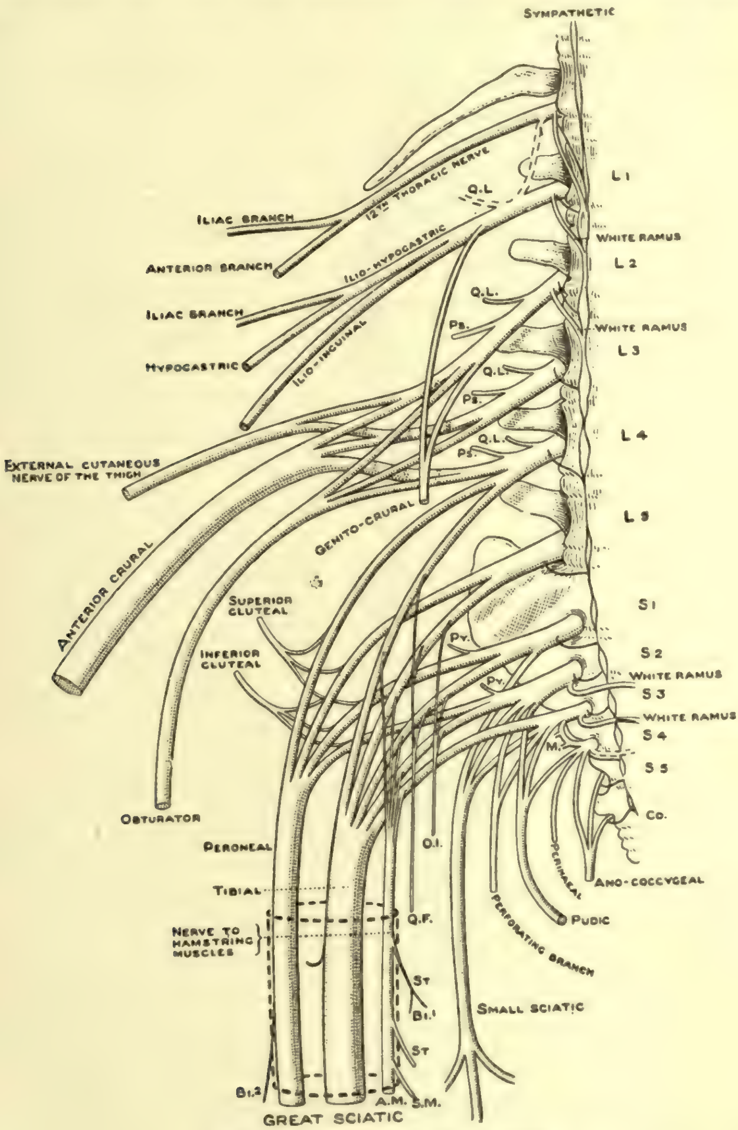


FIG. 24.—Lumbo-sacral plexus.

the external and internal plantar nerves, midway between the internal malleolus and the os calcis. It corresponds to the median and ulnar nerves in the upper limb. It is a larger nerve than the peroneal (Fig. 22)

Course. It extends down the back of the thigh, incorporated for a variable distance with the peroneal nerve in the great sciatic trunk,

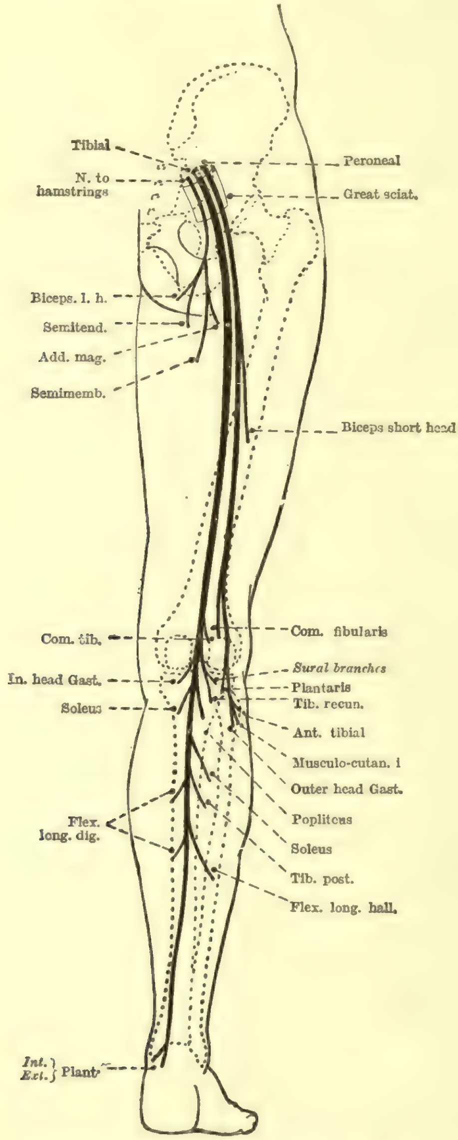


FIG. 25.—Distribution of great sciatic and tibial nerves

under cover of the hamstring muscles. It passes in a vertical direction through the popliteal space, superficial to the vessels.

In the back of the leg the nerve, now known as the *Posterior Tibial Nerve,* is deeply placed beneath the gastrocnemius, soleus, and plantaris,

and accompanies the posterior tibial vessels to the ankle. It lies on the inner side of the posterior tibial artery at its beginning, but is external to the artery at its termination.

Collateral Branches (Fig. 22). (1) In the thigh.

(*a*) A small branch is given off in the upper part of the thigh to the **hip-joint.**

(*b*) Lower down branches are given off to the inner side and back of the **knee-joint.**

(2) In the popliteal space.

(*a*) **Communicans Tibialis.** This branch arises in the popliteal space and passes downwards in the sulcus between the heads of the gastrocnemius muscle. Piercing the deep fascia about the middle of the calf it unites with the **communicans fibularis nerve** from the peroneal nerve to form the **external,** or short, **saphenous nerve.**

The **external saphenous nerve** supplies the lower third of the leg on the outer side, and the outer side of the foot and little toe. In a minority of cases it spreads on to the dorsum of the foot, and may supply the skin of one and a half toes on the outer side of the foot (Fig. 18).

In many cases the two communicating nerves fail to unite. In such cases one is carried to the foot, the other innervating the outer side of the leg.

(*b*) **Muscular Branches.** The tibial nerve gives off branches in the popliteal space to the following muscles:

Gastrocnemius	(each head) (S. 1, 2)
Plantaris	(L. 4, 5, S. 1)
Soleus	(S. 1, 2)
Popliteus	(L. 4, 5, S. 1)

Posterior Tibial Nerve.

At the lower border of the popliteus muscle the tibial or internal popliteal becomes the posterior tibial nerve. It lies at first on the inner side of the posterior tibial artery, but crosses over it in its course down the leg, so that at the ankle it is external to it. The nerve and vessels occupy a sheath of deep fascia formed in the septum between the superficial and deep muscles (Fig. 25).

Collateral Branches. In its course the following branches arise:

(1) **Muscular branches** to:

Soleus	(L. 5, S. 1, 2)
Flexor longus hallucis . . .	(L. 5, S. 1, 2)
Tibialis posticus	(L. 5, S. 1)
Flexor longus digitorum . .	(L. 5, S. 1)

(2) **Cutaneous Branch.** The **Calcanean Nerve** (S. 1, 2) arises in the lower third of the leg and pierces the internal annular ligament close to the

tuberosity of the os calcis. It supplies the skin of the heel and the back part of the sole of the foot (Fig. 18).

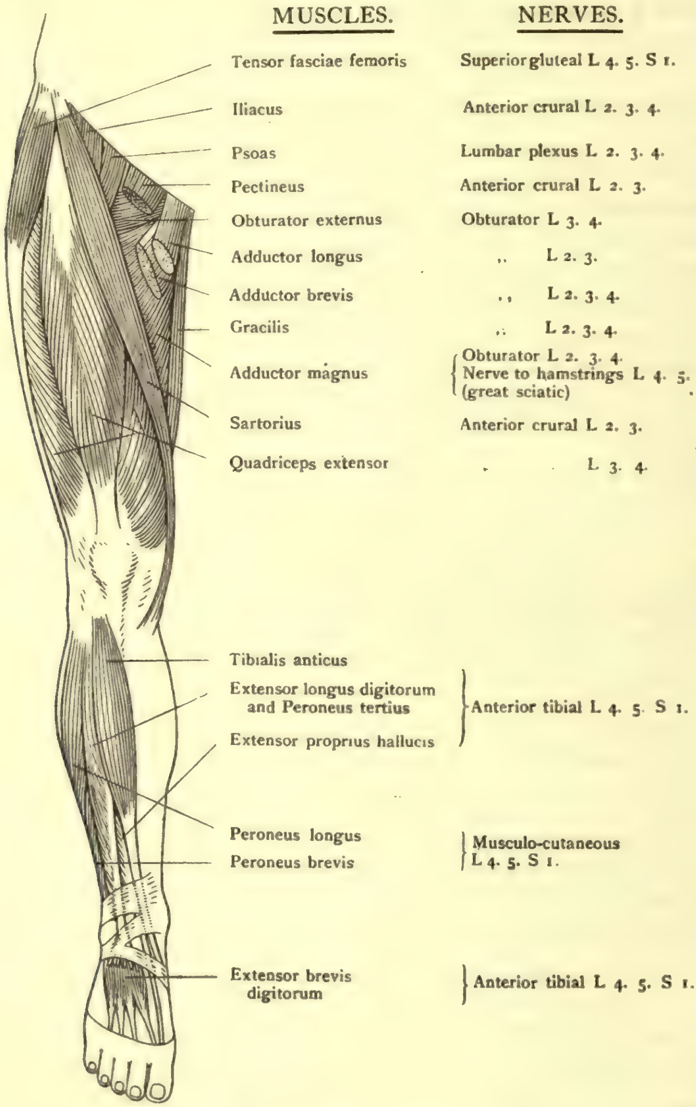


FIG. 26.—Innervation of the muscles of the lower limb.
Front of the limb.

At the ankle, midway between the internal malleolus and the os calcis, the posterior tibial nerve divides into its terminal branches—**internal** and **external plantar nerves.** These correspond in general in their distribu-

tion in the sole of the foot to the median and ulnar nerves in the hand.

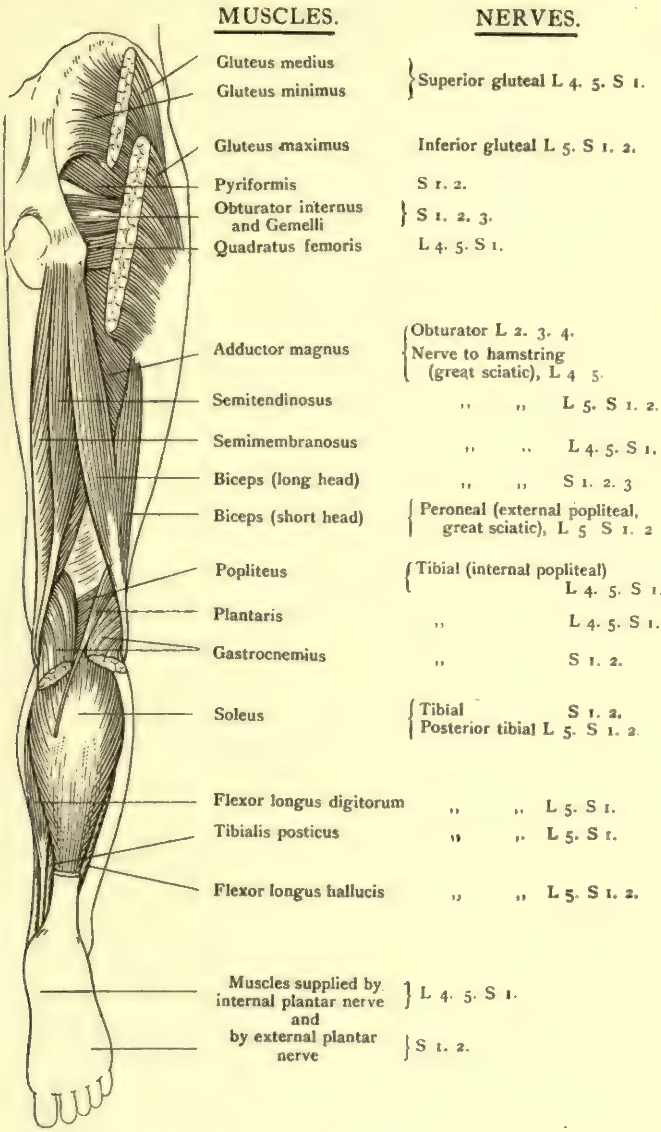


FIG. 27.—Innervation of the muscles of the lower limb. Back of the limb.

The **Internal Plantar Nerve** (L. 4, 5, S. 1) is distributed to the skin of three and a half toes on the inner side of the foot, and sends branches to the dorsum of the terminal phalanges of the corresponding toes.

Muscular Branches are supplied to the following muscles :

Flexor brevis digitorum,
Adductor hallucis,
Flexor brevis hallucis,
First lumbrical muscle.

The **External Plantar Nerve** (S. 1, 2) crosses the sole of the foot obliquely between the first and second layer of muscles. It supplies cutaneous branches to one and a half toes on the outer side of the foot, and is distributed by its deep branch to the muscles of the foot, other than those supplied by the internal plantar nerve.

The Pudendal Plexus

As already stated, the pudendal plexus is formed for the most part by the anterior primary divisions of the spinal nerves behind (caudal to) the lumbo-sacral plexus. The nerve associated with both (*n. bigeminus*) is usually the third sacral nerve (Fig. 28).

In man the plexus is formed by higher nerves as well, so that it overlaps with the sacral portion of the plexus. The nerves forming it are the second, third, fourth, and fifth sacral, and the coccygeal nerve. Occasionally the first sacral nerve is implicated as well. It gives rise to a series of nerves distributed for the most part to the perineum and caudal region. One of its chief trunks, the small sciatic nerve, is also distributed to the skin of the lower limb.

The following nerves arise from this plexus :

Small sciatic	(S. (1) 2, 3)
Perforating cutaneous nerve	(S. 2, 3)
Internal pudic	(S. 2, 3, 4)
Perineal branch of the fourth sacral.	
Muscular branches to levator ani	(S. 3, 4)
Visceral or splanchnic branches	(S. 2, 3, or 3, 4)
Sacro-coccygeal	(S. 4, 5, Co.)

The **Small Sciatic Nerve** (S. (1), 2, 3) passes into the buttock below the pyriformis muscle in company with the inferior gluteal nerve and sciatic artery. Lying on the great sciatic nerve it proceeds to the lower border of the gluteus maximus, where it separates into its terminal branches. It is a purely cutaneous nerve, and supplies three sets of branches :

(1) **Gluteal.** These nerves sweep round the border of the gluteus maximus, and supply a considerable area of the skin of the buttock in its lower part (Fig. 18).

(2) **Perineal.** There are usually several perineal branches which have a wide distribution to the skin of the inner side of the thigh in its upper third, the perineum, scrotum, and penis. One branch, the **long pudendal,**

becomes cutaneous in the anterior part of the perineum, passing between the deep fascia and the pubic arch. It supplies the skin over the anterior part of the perineum, the base of the scrotum, and root of the penis.

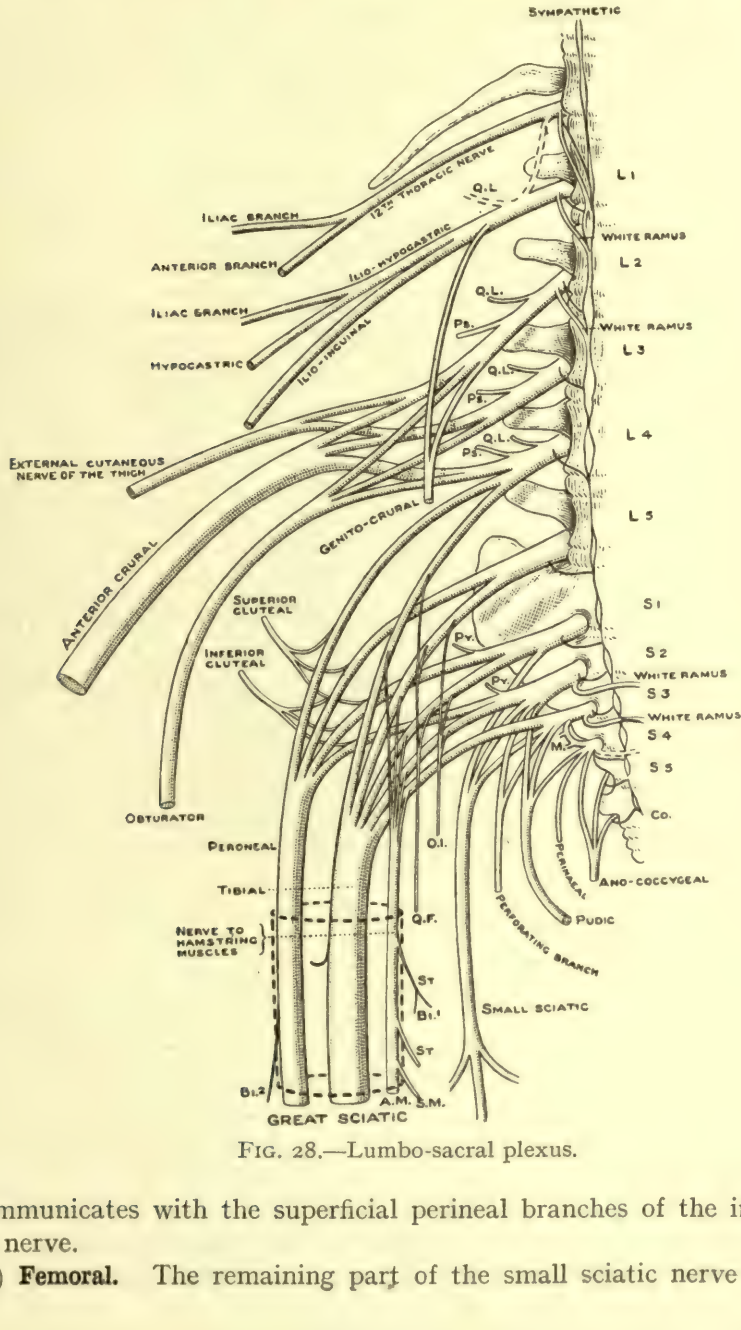


FIG. 28.—Lumbo-sacral plexus.

It communicates with the superficial perineal branches of the internal pudic nerve.

(3) **Femoral.** The remaining part of the small sciatic nerve passes

down the back of the thigh, beneath the fascia lata. It usually divides into two trunks, external and internal, from which twigs arise at irregular intervals to supply the skin of the back of the thigh and popliteal space. The nerve is usually traceable down to the middle of the calf of the leg.

The **Perforating Cutaneous Nerve** arises from the second and third sacral nerves. It is closely associated at its origin with the roots of the small sciatic nerve. After piercing the great sacro-sciatic ligament it winds round the border of the gluteus maximus, and supplies an area of skin over the lower part of the buttock between the areas supplied by the gluteal branches of the small sciatic and the perineal branch of the fourth sacral nerve.

This nerve is not always present, or it may arise from the small sciatic or internal pudic nerve.

The **Internal Pudic Nerve** arises from the anterior surfaces of the second, third, and fourth sacral nerves. Entering the buttock below the pyriformis through the great sacro-sciatic foramen, it crosses the ischial spine, lying on the inner side of the internal pudic artery—to re-enter the pelvis through the small sacro-sciatic foramen. It courses forwards in the outer wall of the ischio-rectal fossa with the pudic artery. They are contained in a special sheath of the fascia covering the obturator internus muscle (Alcock's canal). The nerve passes beneath the triangular ligament of the urethra, and finally divides beneath that ligament into its terminal branches—the **nerve to the corpus cavernosum** of the penis (or clitoris) and the **nerve to the dorsum** of the penis (or clitoris).

The internal pudic nerve is purely a trunk nerve, being distributed solely to the perineum (Fig. 29).

Collateral Branches. (1) **Inferior Hæmorrhoidal Nerve** (S. 3, 4). This nerve arises from the pudic nerve while it occupies the outer wall of the ischio-rectal fossa. Accompanied by the artery of the same name it crosses the ischio-rectal fossa, dividing in its course into a sheaf of branches which are distributed to the external sphincter ani muscle and the skin around the anus. It communicates with the superficial perineal and the long pudendal nerves.

(2) **Superficial Perineal Nerves** (S. 2, 3) posterior or external, anterior or internal. The posterior nerve has the longer course in the ischio-rectal fossa. They both arise from the parent trunk while it is still in Alcock's canal ; leaving the ischio-rectal fossa they pass over or through the transversus perinei muscle, to reach the anterior part of the perineum. They are distributed to the skin of the perineum, the inner side of the thigh, the scrotum, and penis. They communicate with the inferior hæmorrhoidal and long pudendal nerves.

In the female they are distributed mainly to the labia majora.

(3) **Deep Perineal Nerve** (S. 2, 3). This is mainly muscular in its

distribution. Arising from the pudic nerve in the ischio-rectal fossa, just behind the transversus perinei muscle, it proceeds inwards and forwards and divides into branches for the supply of the following muscles : external sphincter ani, levator ani, transversus perinei, bulbo-cavernosus, erector penis, and compressor urethræ. One branch, the **nerve to the bulb,** pierces the bulb of the penis, and supplies the corpus spongiosum and the mucous membrane of the penile portion of the urethra.

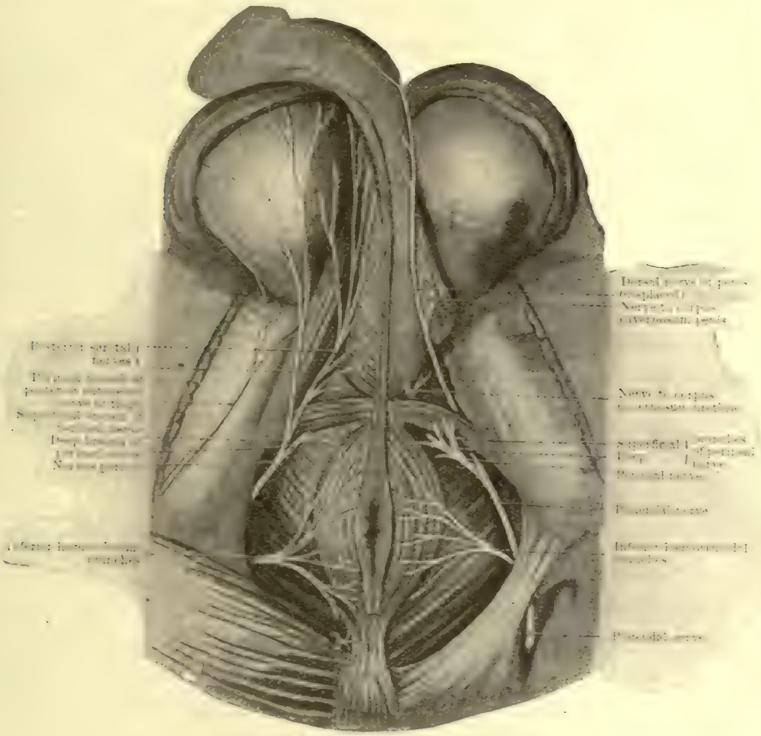


FIG. 29.—Distribution of the pudendal nerve.

The **dorsal nerve** of the penis (or clitoris) may be regarded as the terminal branch of the internal pudic nerve. Passing with the dorsal artery between the layers of the suspensory ligament, it is distributed to the skin of the dorsum and sides of the penis, reaching forward as far as the glans. Some filaments enter and supply the corpus cavernosum.

The **Perineal Branch of the Fourth Sacral Nerve** arises from the front of the parent nerve. It pierces the ischio-coccygeus muscle and appears in the perineum in the angle between the external sphincter and gluteus maximus muscles. It supplies the external sphincter ani muscle and the skin of the perineum behind the anus.

The external sphincter ani muscle is thus innervated by three nerves—deep perineal and inferior hæmorrhoidal from the internal pudic, and by the perineal branch of the fourth sacral nerve.

Branches to the Levator ani Muscle. These nerves arise separately from the front of the third and fourth sacral nerves. They supply the muscle on its visceral surface. The levator ani is also supplied by the deep perineal branch of the internal pudic nerve.

Visceral Nerves (S. 2, 3, or 3, 4). These are pelvic splanchnic or visceral nerves corresponding to the white Rami communicantes of the thoracic and lumbar regions. They differ, however, in an essential feature. They pass *over* the gangliated cord of the sympathetic without being connected with it. They pierce the pelvic fascia alongside the rectum, and become connected at once with the pelvic sympathetic plexus.

Sacro-coccygeal Nerve (S. 4, 5. Co). This represents the **inferior caudal nerve** of tailed animals. It is formed by a part of the fourth sacral, the fifth sacral, and the coccygeal nerves. A rudimentary trunk is formed by the successive union of these small nerves, which is distributed to the skin beside the coccyx.

While to some extent intermingled at their origin with the lumbo-sacral plexus, the nerves of the pudendal plexus are essentially distributed to the perineum and caudal regions—behind the proper attachment of the limb. The perineum in its innervation represents the junction of the distribution of the anterior terminal branches of the anterior primary divisions of the nerves which supply the trunk in front of and behind the limb.

The first lumbar nerve, represented by the ilio-inguinal, sweeps down in front of the limb (along its pre-axial border) and reaches the root of the penis and the base of the scrotum. The other nerves supplying the perineum—small sciatic, perforating cutaneous, internal pudic, perineal branch of the fourth sacral, and the sacro-coccygeal nerves—reach the perineum from behind the attachment of the limb, along its post-axial border. These nerves are derived from the last four sacral and coccygeal nerves.

In the case of the upper limb and lower limb alike the limb is as it were thrust out from the trunk, carrying with it the whole of the anterior primary division of each spinal nerve supplying it, except at its borders, where trunk nerves are carried out in part to supply the skin along the pre-axial, and more particularly along the post-axial borders (intercosto-humeral and small sciatic nerves).

DIAGNOSIS OF INJURIES OF THE PERIPHERAL NERVES

BY

T. GRAINGER STEWART AND W. ROWLEY BRISTOW

DIAGNOSIS OF INJURIES OF THE PERIPHERAL NERVES

DIAGNOSIS AND LOCALIZATION OF LESIONS OF PERIPHERAL NERVES

In order to arrive at a decision as to the proper line of treatment to be adopted in any case of peripheral nerve lesion it is necessary:

(1) To diagnose the nature and severity of the lesion;

(2) To localize the seat of the lesion.

The diagnosis of the nature and severity of the lesion can only be arrived at by a careful consideration of the mode of onset in each individual case and a close analysis of the symptoms and signs revealed on clinical examination. A knowledge of the mode of onset of the symptoms, its relation to illness or injury, may serve at once to determine between injury or disease as the cause of the paralysis.

The severity of the lesion can only be gauged by a knowledge of the signs and symptoms characteristic of complete division, compression, or irritation of a nerve, and of the clinical signs which denote the occurrence of nerve degeneration. Further, it is necessary to appreciate the changes which take place in the clinical picture which may be taken as indicating recovery.

The correct localization of the seat of the lesion can only be made by applying a knowledge of anatomy and physiology to the unravelling of the signs and symptoms present in each individual case.

GENERAL PRINCIPLES WHICH MAY BE TAKEN AS A GUIDE IN FORMING AN OPINION AS TO THE NATURE AND SEVERITY OF THE NERVE LESION

This chapter is devoted to a brief consideration of the general principles which must guide one in forming an opinion as to the nature of the nerve lesion.

Time of Onset of Nerve Symptoms in Relation to the Time of Injury.

Symptoms of nerve injury arising immediately on receipt of a gunshot wound indicate that the nerve has been either divided, torn, bruised, concussed, or compressed.

Symptoms of nerve injury developing subsequently, but in relation to the seat of injury, indicate that the nerve has become affected in one of the following ways: (*a*) by involvement in scar tissue, (*b*) by the formation of adhesions between the nerve sheath and the surrounding

parts, (*c*) by the formation of callus, (*d*) by pressure due to stretching of the nerve over displaced fractured bones, or new outgrowth of bone, (*e*) by pressure from splints or crutches, (*f*) by intraneural changes, either the formation of interstitial scar tissue, or the involvement of the nerve by sepsis.

Symptoms arising independently of any known injury may be due to (*a*) crutch or pressure paralysis, (*b*) neuritis of toxic origin, (*c*) involvement of the nerve by tumour, aneurism, or pressure from cervical rib, or (*d*) may herald the onset of acute or chronic disease of the central nervous system, such as acute anterior poliomyelitis, progressive muscular atrophy, or syringo-myelia, (*e*) the development of some latent form of myopathy, (*f*) functional paralysis.

Functional paralysis has been dealt with elsewhere, and therefore in this article reference will only be made to it when considered necessary. It cannot, however, be too strongly emphasized that functional paralysis may develop at any time and that it may occur, either alone, or in conjunction with, an organic lesion of one or more nerves. It is not uncommon, for instance, in cases of injury to the musculo-spiral nerve to find at the first examination definite evidence of organic injury to the musculo-spiral nerve with signs of functional paralysis of the whole of the arm below the level of the external wounds—namely, paralysis with impairment or loss of voluntary movement and loss of sensation up to the level of the wound, but with unimpaired electrical reactions except in the case of the extensor muscles.

Important as is the consideration of the time of onset of the nerve symptoms in relation to the time of the injury, as a guide to the probable type of nerve injury, it is by itself of little aid in determining the severity of the lesion. In order to do so it is necessary to have a general idea of the symptoms and signs produced by complete division of a nerve, by incomplete division of a nerve, by irritation, and further, to be able to recognize the signs and symptoms which point to recovery.

Symptoms and Signs produced by Complete Division of a Peripheral Nerve.

Motor.—(1) The immediate onset of complete and total paralysis of the muscles supplied by the divided nerve below the level of the lesion.

(2) The immediate onset of loss of tone in the paralysed muscles, which rapidly culminates in complete hypotonia, characterized by softness and flaccidity of the muscles on palpation, and by the posture of the paralysed limb.

(3) The loss of the tendon reflexes of the paralysed muscles.

(4) The onset of wasting in the paralysed muscles with well-marked trophy.

(5) A temporary increase in the mechanical excitability of the paralysed muscles.

(6) Changes in the electrical reactions as follows :

(*a*) Immediate loss of excitability on stimulation of the nerve above the level of the lesion.

(*b*) Progressive diminution in the faradic excitability of the paralysed muscles, and of the nerve below the level of the lesion, resulting ultimately in complete loss of faradic excitability in from one to six weeks.

(*c*) The galvanic response becomes sluggish, and a stronger current is required to induce contraction.

Sensory.—(1) The immediate onset of sensory loss in the area of distribution of the divided nerve. In the case of a mixed nerve the sensory loss will be found both in the cutaneous and deep sensory areas supplied by the nerve. At first the area of sensory loss may be greater than that found later on, but it will remain constant in those portions of the nerve distribution in which there is no sensory overlap from the adjoining nerves.

(2) By the absence of pain on pressure on the muscles supplied by the nerve below the site of the lesion, and by the absence of distal tingling in the nerve area on percussion of the nerve below the level of the lesion. By the presence of distal tingling on percussion at the level of the lesion.

Trophic.—By the absence of serious vaso-motor and trophic disturbances in the skin, nails, joints, and tendons, except those due to accidental extraneous injuries such as burns or pressure lesions in the anæsthetic areas.

Symptoms and Signs of Incomplete (Compression) Lesion without Loss of Anatomical Continuity.

The type of lesion which falls under this head is that seen in the compression of a nerve, either from pressure as in crutch palsy or from an injury which compresses but does not sever the axis cylinders.

Motor.—(1) The immediate onset of paralysis, total or incomplete, in the muscles supplied by the injured nerve.

(2) The gradual onset of incomplete loss of tone in the paralysed muscles.

(3) Diminution or temporary loss of the tendon reflexes.

(4) The relatively rapid onset of atrophy in the paralysed muscles, of less severity, however, than in complete division of the nerve, and accompanied by a marked increase in their mechanical excitability.

(5) Changes in the electrical reactions.

(*a*) Faradic stimulation of the nerve above the site of the lesion may cause contraction of the paralysed muscles.

(*b*) Faradic stimulation of the nerves and muscles below the lesion may cause a partial, sluggish, and feeble contraction of the muscles supplied, and this may never disappear, or, on the other hand, may become lost, if progressive degeneration sets in at the site of the injury.

(*c*) Galvanic stimulation may result in an unduly rapid but feeble muscular contraction, or in a slow, feeble, prolonged contraction.

Sensory.—(1) The presence of anæsthesia which is variable in degree and, to a less extent, in area, within the distribution of the injured nerve.

(2) The absence of pain on pressure on the nerve below the level of the lesion, and the absence of distal tingling on percussion over the nerve below the level of the injury.

Trophic.—The absence of trophic and vaso-motor disturbance in the skin, nails, joints, &c. in non-irritative lesions.

Although it is possible for a nerve to remain in a state of physiological interruption without solution of anatomical continuity, for some weeks or months, yet careful examination will generally reveal the development of signs and symptoms pointing either to the occurrence of complete interruption, or of partial or complete recovery. It is obvious, therefore, that only by the comparison of repeated complete and detailed examinations extending over a considerable period, will the surgeon or physician be able to form an opinion as to the likelihood of recovery without surgical interference.

Signs and Symptoms of Nerve Irritation.

These vary widely in character and severity.

Motor.—(1) As a rule voluntary power is present, but it is not uncommon to find varying degrees of paralysis in the muscles supplied by the affected nerve.

(2) The onset of the paralysis may be immediate, but sometimes it develops two or three weeks after the injury.

(3) There is little or no loss of tone, and indeed in some cases the tone of the muscles is increased.

(4) The tendon reflexes may be retained.

(5) Muscular atrophy may, or may not, be present, and is often very irregular in its distribution, some muscles or parts of muscles escaping whilst others are atrophied. The atrophy which does occur may develop very rapidly or come on slowly.

(6) The mechanical irritability of the muscles is increased.

(7) Changes in the electrical reactions.

(*a*) Faradic response may be present, normal in some muscles, impaired in others.

(*b*) Galvanic response may be brisk but feeble, or sluggish.

Sensory.—The most characteristic feature of the sensory disturbances is the occurrence of spontaneous pain, and the existence of hyperæsthesia and hyperalgesia.

Spontaneous Pain.—This usually comes on immediately, and often causes the patient to think that he has been wounded somewhere in the area of distribution of the sensory fibres. For example, a man whose sciatic nerve was injured in the region of the thigh, thought he had been hit in his foot ; or again, a man whose median nerve was injured in the upper arm, thought that the bullet had passed through his hand. In other cases, however, the onset of pain may be delayed for from two to four weeks, and then gradually develop and increase in severity. The pain may be constant and vary only in intensity, gradually becoming very severe and excruciating. As a rule any noise, jar, or fright will accentuate the pain, and any sudden movement may cause a spasm. The pain may be aggravated by posture, such as the dependent position of the limb. Heat as a rule increases and cold diminishes the pain, though there are exceptions to this rule. Variations in temperature also tend to aggravate the pain. Exposure to the air is as a rule painful, and the greatest comfort is obtained by keeping the peripheral area covered up in wet cloths.

The pain is usually described as being of a burning stabbing character, and is generally not well localized. Its distribution is often over an area greater than the normal distribution of the affected nerve, but its chief intensity is always referred to a point or points within the area of distribution.

The Sensory Examination of these cases is often most difficult owing to the pain which such examination may cause, and also because suffering has undermined the morale of the patient.

Cutaneous Sensibility.—As a rule there is hyperæsthesia and hyperalgesia—cotton-wool, pinprick, or heat and cold causing severe pain of peculiar character, not recognized as being like any normal kind of pain, and not localized to the point stimulated. In some cases there is hypoæsthesia, in others hyperæsthesia with diminished sensibility to heat and cold, and sometimes to pinprick. The area of disturbance will correspond to that of the affected nerve, although sometimes it is limited to one portion of the area.

Deep Sensibility.—The nerves and muscles are tender to pressure and as a rule deep sensibility is not lost. In cases of causalgia deep pressure may not cause any pain although light touch cannot be borne.

Trophic.—In cases of nerve irritation, especially when of a severe type, trophic disturbances are invariably present. In the skin a condition of fine powdery desquamation or of coarse scaley desquamation often

associated with œdema may be present, or in contrast, the skin may be sodden and give off a fœtid odour. In other cases the skin is fine and glossy and of a pinkish-red colour or moist and sweat bedewed without much desquamation.

The bones of the fingers atrophy, the hands become tapered, the nails may become curved, furrowed and claw like, or brittle and frayed; in other cases they become opaque and sodden looking with frayed ends and often with a collection of white desquamating epithelium under their ends, a condition which is invariably associated with great tenderness of the finger tips.

Fibrous infiltration of the skin, fascia, peri-articular structures and even of the muscles may develop rapidly. If this condition does not receive appropriate treatment fibrous ankylosis and deformities result.

In the less severe types of nerve irritation the motor and trophic changes may be slight and it is the pain and sensory disturbances which point to the presence of nerve irritation. In these cases, however, Levick has demonstrated that a myographic tracing of the muscle contractions will show a lengthening of the period of decontraction.

Symptoms and Signs of Nerve Regeneration.

Nerve regeneration is a gradual process and is accomplished by the downward growth of axis cylinders from the central end. The rapidity of their growth will depend partly on the age and general health of the patient, also to a great extent upon the condition of the tissue through which they have to pass to join up with the central end of the distal portion of the nerve. If the divided ends can be brought together in a healthy state, recovery may be rapid; if, on the other hand, the axis cylinders have to pass through scar tissue, regeneration will be delayed if not entirely prevented.

Motor.—The symptoms and signs of recovery in the muscles are: (1) Restoration of muscle tone. This is a gradual process but is one of the early signs, (2) restoration of muscle sensibility, (3) diminution of muscle atrophy, (4) return of voluntary power.

Changes in the electrical reactions are (1) an improvement in the galvanic reaction, although too much stress must not be laid upon this, (2) the restoration of faradic excitability. These changes will, as a rule, be found first in the proximal muscles later extending to the more distal.

Sensory.—(1) The occurrence of pain, and tingling sensations in the cutaneous distribution of the nerve.

(2) The restoration of cutaneous sensibility firstly of protopathic sensibility—pinprick and heat and cold—and secondly of epicritic

sensibility—cotton-wool and localization. The recovery takes place as a rule first in the proximal portions of the nerve area, and then in the more distal. Thus in the proximal parts both epicritic and protopathic sensibility may have recovered, whilst in the distal portions protopathic only may be recovering. For information as regards the rate of recovery the reader is referred to the section on Prognosis.

Trophic.—With the recovery of protopathic sensibility trophic ulcers heal and there is a marked improvement in the condition of the integuments, bones, and muscles. But where fibrous changes have involved the deeper structures, it is only by persistent treatment that the resulting disability will be overcome and deformities corrected.

CLINICAL EXAMINATION

In making the clinical examination of a case of nerve injury it is well to follow a routine method, as by so doing, points which may afterwards prove to be of great assistance in deciding upon treatment, will not be overlooked and the examination itself will be more easily and thoroughly carried out.

History. The first step is to obtain as accurate a history as is possible in regard to the following points:

(1) The date of the injury and how received.

(2) The position of the patient and his limbs at the time he was hit and if possible the direction in which the bullet was travelling.

(3) The immediate effects of the injury as regards loss of power or paralysis ; the occurrence of pain at the time, and the area in which the pain was felt ; anæsthesia and its distribution. Inquiry should also be made as to whether there was severe hæmorrhage necessitating the ligaturing of any large vessels ; and further, as to whether there was any injury to joints or bones.

(4) The subsequent effects of the injury as regards

Motor System. Whether there has been any change in the degree or extent of the paralysis noted at the time of injury, either in the direction of diminution or increase ; or whether paralysis and loss of power have developed subsequently, and if so when it was first noticed and its rate of progress. The presence or absence of muscular wasting must be noted.

Sensory System. Whether the immediate pain has disappeared or if still present whether it has increased or abated in intensity and extent. Whether there has been any subsequent pain, and, if so, its mode of onset and distribution. Inquiry should also be made as to whether there has been any return of sensibility or loss of sensibility since the injury was received.

In cases where bones and joints have been injured, inquiry should be

made as to when the wounds healed, the position of the fracture, if any, and date of union, the presence or absence of callus, and whether any permanent deformity or ankylosis of joints has taken place.

Inquiry should be made as to the condition of the wound, as regards sepsis and the date of healing.

(5) The subsequent treatment of the injury. Inquiry should be made as to the treatment, surgical and medical, and whether massage, movements, and electrical treatment have been carried out ; if operation has been performed, the date of operation, what was found, and what procedures were adopted.

Examination of the limb.

(*a*) First examine the site of the scars, noting the direction of the wound and taking into consideration the position of the patient at the time he was hit. This may afford some idea of the structures likely to have been damaged.

(*b*) Observe the position of the limb and note its general appearance. The position of the limb may be determined by several factors—paralysis, fracture, ankylosis, or secondary contractures from prolonged splinting, over-action of non-paralysed muscles or contraction of paralysed muscles. Any or all of these factors may be acting in any individual case.

(*c*) The presence or absence of muscular wasting should be noted, but it must not be forgotten that in recent cases muscular atrophy may not have developed or it may be obscured by œdema and swelling of the limb. In old-standing cases atrophy may be noticed in muscles not affected by nerve injury due to disuse and inaction of the limb as the result of the injury.

(*d*) The vasomotor condition of the limb should be examined, with reference to the presence or absence of arterial pulsation ; the presence or absence of œdema, its extent and whether it can be accounted for by some cause such as splinting or posture. The colour and temperature of the limb should be noted, due care being taken to consider the external temperature as a warm or cold day exercises a great effect on the appearance of the limb. The condition of the skin, and sweat glands should also be noted.

Motor System. The examination of the motor system may be divided into two parts, (*a*) clinical, and (*b*) electrical.

The clinical examination will commence with the investigation of the degree of voluntary movement present in each case. Before commencing to test the voluntary movement make certain that you have, by passively moving the various joints, made yourself acquainted with the possible range of movement at each. No part of the clinical examination

is more difficult than the testing for voluntary movement because many movements carried out usually by one muscle, or group of muscles acting together, can be partially carried out or simulated by the action of other muscles. Voluntary movements are initiated in the higher centres and the motor nerves merely transmit the impulses to the muscles. Many voluntary movements, therefore, are carried out by muscles supplied by different nerves, and the modifications of any such movement owing to paralysis of certain muscles are obviously variable. Further, certain patients may simulate a movement by calling into action some non-paralysed muscles which may in part supply the action of the paralysed ones. It is only by experience that one can learn to know the traps which are set for the unwary but fortunately the electrical examination will in almost every case give a true interpretation to what may appear to be a correct, but is in reality an incorrect observation.

After having examined the voluntary movement first test the tone of the muscles where possible, by noting the condition of the tendon reflexes. Next note the mechanical excitability of the muscles to a direct stimulus—the tap of a percussion hammer. It will often be observed that there is a great increase in the mechanical excitability of a muscle which is in a hypotonic condition. The distribution of the wasting, if any, should be noted. A knowledge of anatomy will enable one to locate the site of the injury—whether in a nerve, cord, trunk, or root.

If on examination no voluntary movement is observed and no obvious reason for this can be detected, such as muscular wasting, loss of deep reflexes, &c., it will be necessary to examine the muscle reactions electrically in order to find out whether the loss of movement is of functional or organic or mixed origin. If the loss of movement is due to a peripheral lesion the changes in the electrical reactions will solve the problem. In order to make the diagnosis between a functional paralysis and one due to lesion of the upper motor neurone, it is necessary to examine the patient's nervous system carefully, and a diagnosis of purely functional paralysis should not be made unless there is no evidence of organic disease.

Sensory System. The examination of the sensory changes present in any case, supplies the complement to the motor examination. The observer must have infinite patience and the patient must be intelligent and not bored or distracted by other things. Further, a detailed sensory examination is very tiring to both observer and patient, and when pressure of work limits the time available for the examination of each case a practical method, not too detailed, should be used.

The examination of the sensory system may be divided into two

parts. Firstly, a consideration of the sensory disturbances complained of by the patient, and secondly, a study of the defects in sensibility discovered by testing. Inquiry should be made as to the occurrence, past or present, of pain, numbness or tingling, and its time of onset, character, distribution noted. The effect of posture, varying temperatures, touch or pressure should also be noted.

The testing of sensibility has as its object the mapping out of the area as regards its extent and the quality of the sensory change. Every examination should be so complete that it will form a standard for comparison with later investigations.

Peripheral sensibility is divided into two main groups—cutaneous or superficial, and deep.

Cutaneous sensibility includes sensibility to

Light touch. Moderate degrees of temperature between 25° and 40° C. Localization of touch. Discrimination of two points.	Epicritic.
Cutaneous pain—pinprick or pulling a hair. Extremes of temperature between 20° C. and above 45° C.	Protopathic.

Deep sensibility includes—

Sense of position.
Deep pain—muscles and bones.
Vibration.

After division of a mixed nerve and subsequent successful suture, there is first a restoration of deep sensibility, then of protopathic sensibility, and later on of epicritic. The time at which recovery takes place varies according to the particular nerve, the site of lesion, and the general health of the patient.

Methods of Testing.

In testing sensation the patient should be in a quiet room where his attention will not be distracted. He should be placed in a comfortable position and then made to close his eyes or have them covered so that he cannot see the part which is being tested.

When mapping out anæsthesia it is best to start from the anæsthetic area and work towards the normal. The points at which he feels can be marked with a skin pencil, different signs being used to denote appreciation of touch, pain, heat, and cold. These marks can then be joined together and the result copied on to a chart.

In testing hyperæsthesia, on the other hand, work from the normal towards the hyperæsthetic area.

Light Touch can be tested with a piece of cotton-wool or a fine brush, which do not depress the skin.

Pain can be tested by pricking or scratching with a sharp needle.

Cold and Heat can be investigated by using test-tubes containing ice-cold and hot water, and, when using the hot test, in order to retain the heat the test-tube should be corked. The temperature should be about 50° Centigrade.

Moderate Degrees of temperature between 25° and 40° C. can easily be tested by using metal spoons of different temperatures.

Pressure can be tested by means of a blunt pencil or the point of the finger.

Pressure Pain by deep pressure can, if necessary, be measured with an algometer.

Sense of Position can be tested by fixing the limb proximally and then grasping the limb or finger on the distal side of the joints to be tested by their lateral surfaces, and then flexing or extending the joints; if possible the patient should be asked to indicate the position by placing the corresponding limb or finger in a similar position.

Vibration is tested by applying a vibrating tuning-fork of fairly large size to the bones or muscles.

By careful examination a chart can be mapped out showing the quality and extent of the sensory loss. The quality of the sensory loss may enable one to form an opinion as to the completeness of the nerve lesion and to a less extent of its site. The nearer the lesion is to the spinal cord the more closely do the areas of loss to epicritic and protopathic sensibility approach each other. In nerve lesions, the area of epicritic loss is greater than the area of protopathic loss; in root lesions, on the other hand, the area of protopathic loss is greater or as great as the area of epicritic loss. In an incomplete nerve lesion or in recovering nerve lesions, there may be little or no loss of protopathic sensibility whilst there is complete loss of epicritic sensibility.

In the section devoted to the Localization of Nerve Injuries, charts are given showing approximately the area supplied by the different sensory roots and nerves.

ELECTRO-DIAGNOSIS

Muscle Testing. It must be clearly understood that the electrical findings in a case of nerve injury, though essential to a complete investigation of the condition, do not in themselves suffice for diagnosis. 'The electrical examination is the indispensable adjunct to the clinical examination.' The findings required by the surgeon are the responses to the faradic and galvanic currents. If the electro-therapist considers

it necessary or desirable, he may add to the report the result of the examination by the condenser discharge method, but this should never take the place of the routine examination by the faradic and galvanic currents. There are some elaborate methods—for example, investigation with the Lapicque chronaximeter—but these are more suitable for the physiological laboratory than for a busy hospital department.

The report to be furnished to the surgeon or written on the notes, must be such that it will help the clinician in forming a diagnosis. The form which such a report should take is a matter of some importance. The most useful is somewhat as follows: 'Muscles supplied by musculo-spiral nerve, below triceps no faradic response, sluggish galvanic response, i.e. R.D.'

The electro-therapist should make a point of attending operations and so checking his own diagncsis until he has gained experience and become thoroughly competent. If any case presents points of difficulty or he is not absolutely certain about some of the reactions, he should invariably be present at the operation.

Moreover, it may be necessary for him to test a case several times before he can be sure of the electrical reactions. Preliminary massage and warming of the part will materially aid the investigation.

The routine examination is carried out by using a combined table with a faradic and galvanic switchboard, and a metronome interrupter. It is advisable to test by the di-polar method, using two small electrodes. This method concentrates the stimulus on the paralysed muscles and largely prevents the spread of the current to the non-paralysed opponents. It will also enable the contractions to be obtained when the muscle is much degenerated, and no response is obtainable by the uni-polar method. The sole objection is that it does not allow the response to the anode and cathode to be investigated, but this is a matter of no clinical importance. The combined table is arranged so that only two connecting cords lead off to the patient and two switches enable the operator to throw in the faradic or galvanic without changing the terminals in any way. The muscle is first examined with the faradic current, and if faradic response is obtained, this suffices, and no further investigation of the case need be made from the electrical point of view. It is quite true in some cases that the faradic response may be present, and at the same time there is some slight alteration in the galvanic response, which is evidence of slight injury to the nerve. Faradic response, if obtained, will at once clear up any doubts as to the functional or organic nature of the lesion, and, moreover, in combined lesions, will assist in differentiating organic from functional elements.

It is only by constant practice that a sound working knowledge of electrical testing can be acquired, and the fallacies and small difficulties overcome.

THE TECHNIQUE OF TESTING

The part to be examined should first of all be soaked in a bath of warm water in order to lower the skin resistance, and so make the passage of the current easier. Care must be taken to avoid producing burns when dealing with the area which is anæsthetic, or in which trophic changes have developed. In these cases the preliminary heating must be omitted. Before making the examination, it is necessary to see that the instrument is working correctly and also to test the strength of the current on the examiner's own hand before applying it to the patient. The weakest faradic current which will cause contraction is used. If no contraction is obtained, the strength of the current is increased as far as the patient will tolerate, or until it is so strong that it spreads to the surrounding non-paralysed muscles. The findings are then recorded. The points selected for stimulation are the motor points, the two electrodes being placed on the muscles, one on the motor point and one lower down, or one on the muscle and one on the nerve; the latter method is applicable to cases in which the nerve is close to the surface, as, for example, the external popliteal behind the head of the fibula or the musculo-spiral in the arm.

The galvanic test is carried out in the same way with the same two electrodes. They are both placed on the muscle ; one in the neighbourhood of the motor point, and the other lower down on the tendon. With the galvanic it is the type of contraction which gives the clue to the situation. The normal galvanic contraction is a quick twitch. In the case of impairment of the lower motor neuron the contraction period remains the same, or nearly so, but the relaxation period is very markedly prolonged, and the galvanic response is therefore said to be slow or sluggish. The smallest amount of current which will produce contraction is used, as with the faradic, and again, if no contraction is obtained, the current is increased to the toleration of the patient, or until the stimulation affects the neighbouring healthy muscles. By use of the di-polar, as opposed to the uni-polar method, the stimulation is more strictly limited to the paralysed group.

CHRONAXIE

The scientific explanation of the behaviour of muscles and nerves on stimulation by electricity depends on the phenomenon known as the chronaxie. In order that any response may be obtained two factors are necessary :

1. That the stimulus be only of sufficient strength; i.e. a minimal stimulus.
2. That it acts for a sufficient length of time; that is to say, a minimal duration.

In practical physiological work the minimal stimulus is found and given a certain value, and by means of a delicate electrical instrument, the duration of such stimulus is ascertained in any particular case. This is the chronaxie. The normal nerve, when stimulated, will respond to stimuli of very short duration, one-thousandth of a second. After the division of the nerve the muscle requires stimulating for a much longer time, one-hundredth or one-fiftieth of a second, in order that it may contract. In other words, the chronaxie of the nerve is about one-thousandth, and that of the muscle one-hundredth. Now the duration of the stimulus of an ordinary faradic coil is about one-thousandth of a second, and it is for this reason that the normal muscle will respond to faradic stimulus, while the paralysed muscle, in which the stimulus is to the muscle direct, and not through the nerve, fails to react, because it requires a duration of about one-hundredth of a second or longer to provoke response.

REGIONAL DIAGNOSIS

THE UPPER EXTREMITY

THE BRACHIAL PLEXUS

The nerves of distribution to the upper limb are formed by the brachial plexus. The plexus is situated in the posterior triangle of the neck and in the axilla. The nerves composing the plexus are the anterior primary divisions of the last four cervical nerves and the greater part of the first thoracic. The cervical nerves increase in size from above downwards. A small branch of communication passes from the fourth to the fifth cervical, and in the majority of cases there is a considerable intrathoracic communication between the first and second thoracic nerves.

The first thoracic nerve, after supplying a small intercostal branch for the supply of the muscles of the first intercostal space, and receiving a trunk of communication from the second thoracic nerve, passes over the neck of the first rib, alongside the superior intercostal artery, and becomes closely associated with the eighth cervical nerve between the scalene muscles.

The constituent nerves emerge in the neck between the scalenus anticus and scalenus medius muscles, in close relation to the subclavian artery. The fifth, sixth, and seventh nerves are above, and the eighth cervical and first thoracic are directly behind the artery.

There are four stages in the formation of the plexus and the nerves of distribution :

(1) The junction of the five separate nerves into three definite trunks. The fifth and sixth cervical nerves join together to form the upper trunk ; the seventh runs by itself as the middle trunk ; and the eighth cervical and first dorsal are united into the lower trunk.

(2) The subdivision of the trunks into anterior and posterior divisions.

(3) The reunion of these divisions into three cords. The anterior divisions of the upper and middle trunks unite to form the outer cord ; the anterior division of the lower trunk runs alone as the inner cord ; and the posterior divisions of all the trunks unite to form the posterior cord.

(4) The formation of collateral and terminal nerves of distribution to the limb from these cords.

In reality each nerve trunk retains its individuality in these ' cords ', and subdivides and again re-unites, by means of its subdivisions, with neighbouring trunks, to produce collateral and terminal nerves of distribution.

Nerves of Distribution. In addition to the terminal branches distributed to the upper limb, which will be described later when dealing with the individual nerves, two series of collateral branches are given off by the nerves of the plexus, one set above, and one below the clavicle.

Collateral Branches

Supraclavicular Nerve.	*Origin.*	*Distribution.*
Nerve to subclavius . .	C. 5. 6	Subclavius muscle.
Suprascapular . . .	C. 5. 6	Supraspinatus. Infraspinatus.
Posterior scapular. N. to Rhomboids	C. 5	Rhomboids. Levator anguli scapular.
Posterior thoraic nerve .	C. 5. 6. 7	Serratus magnus.
Infraclavicular		
External anterior thoracic .	C. 5. 6. 7	Pectoralis major and minor.
Internal anterior thoracic .	C. 8	Pectoralis major and minor.
Circumflex	C. 5. 6	Deltoid. Teres minor.
Short subscapular nerves .	C. 5. 6	Subscapularis.
Lower subscapular nerves .	C. 5. 6	Subscapularis. Teres major.
Long subscapular nerves .	C. 6. 7. 8	Latissimus dorsi.

Two points of practical interest are worthy of mention, namely the relationship of the roots, trunks, and cords to the surface anatomy, and the relationship of the brachial plexus to the axillary artery and vein.

The roots, after emerging from the spinal column, pass outwards towards the apex of the axilla ; the upper downwards and outwards, the lower more horizontally. The plexus, therefore, forms a triangle, the base of which is parallel to the spinal column and the apex at the

upper end of the axilla. At their points of emergence from the spine the roots are more or less widely separated, but as they pass downwards and outwards, they come into closer relationship.

Wounds in the region of the axilla must therefore almost of necessity involve several nerves, whereas wounds near the vertebral column may damage only one or two roots.

The primary trunks lie in the region of the supraclavicular fossa and the cords are formed below the clavicle.

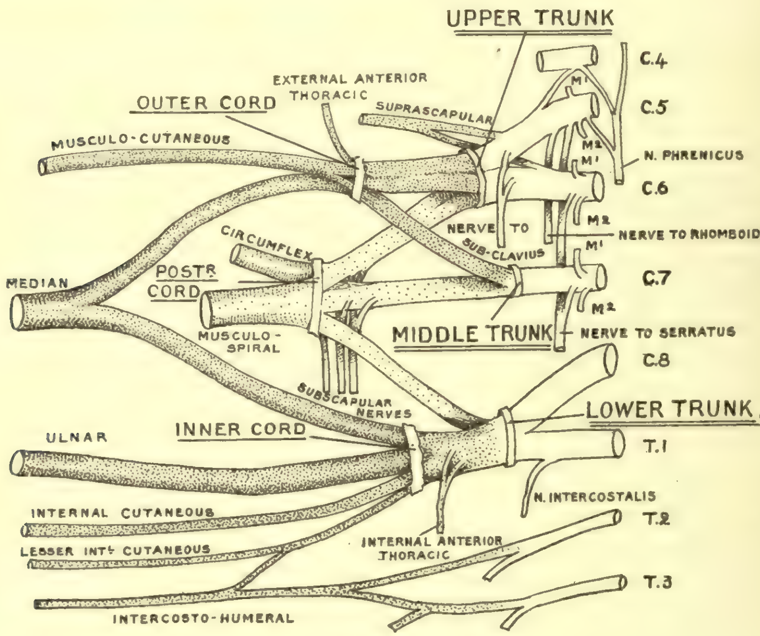


FIG. 30.—The brachial plexus.

The relationship of the plexus to the axillary artery and vein is important. In the upper part the cords lie external and slightly posterior to the artery which lies between them and the vein. The musculo-cutaneous nerve lies on the outer side of the artery, the median in front and to the outer side, the musculo-spiral behind, the ulnar between the artery and the vein; the inner head of the median passes between the artery and the vein and crosses in front of the artery to join the outer head.

Gunshot injuries in this region may prove fatal unless surgical aid is at hand to stop the hæmorrhage, and in the majority of cases which survive varying degrees of ischæmic paralysis complicate the clinical picture.

Before entering into details of the diagnosis of lesions of the various roots, trunks, cords or nerves, the reader is asked to study the anatomy of the brachial plexus and to make himself familiar with the following diagrams which illustrate the motor and sensory distribution of the roots and nerves of the plexus.

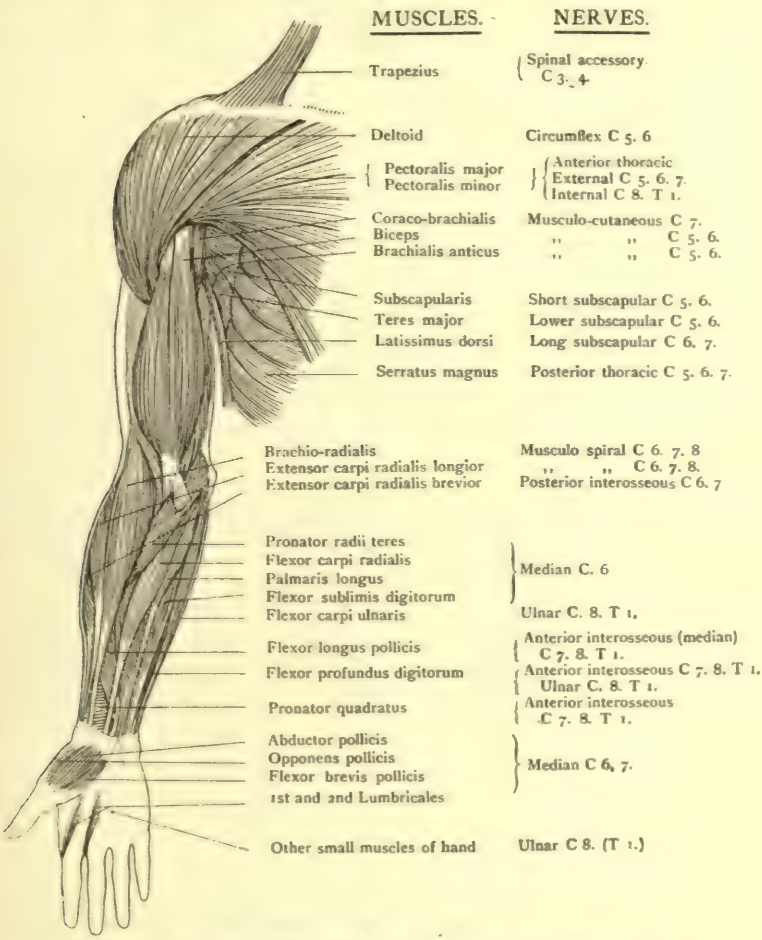


FIG. 31.—Innervation of the muscles of the upper limb. Front of the limb.

Complete Lesions of the Brachial Plexus

A complete lesion is extremely rare, usually one cord will escape at least partially.

Diagnosis. *Motor.*—The arm hangs limply by the side and there is complete paralysis and wasting of all the muscles of the upper extremity with the exception of the levator anguli scapular, the serratus magnus, and the rhomboids. The pectoral muscles are as a rule paralysed.

Sensory.—The area of sensory loss varies somewhat in different cases, but there is loss of cutaneous sensibility over the whole of the hand and forearm and on the upper arm over its outer aspect to near the tip of the shoulder, although generally it does not extend so high ; on the inner surface it extends upwards to about the level of the fold of the axilla.

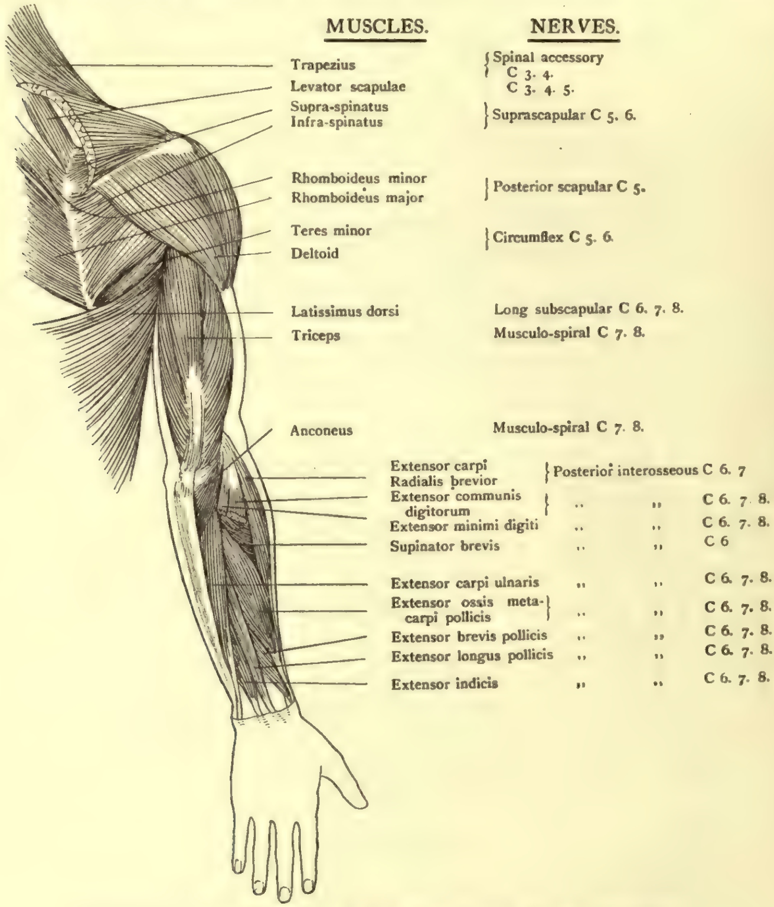


FIG. 32.—Innervation of the muscles of the upper limb. Back of the limb.

There is loss of sense of position at the elbow and below, and loss of deep sensibility in the muscles affected and bones of the forearm and upper arm.

Reflexes.—All the tendon reflexes are abolished.

It is particularly characteristic of brachial plexus injuries that in many cases a lesion which at first appears to be complete gradually shows signs of partial recovery, with the result that the ultimate area of total paralysis may be confined to the upper or lower portions of the plexus.

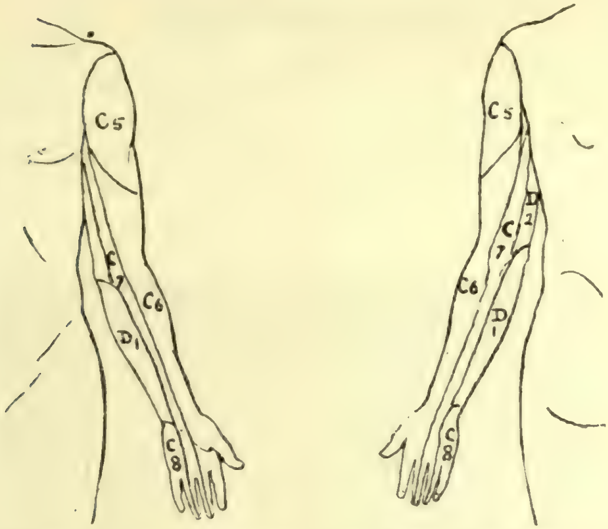


FIG. 33.—Innervation of the skin of the upper limb Areas of distribution of the sensory roots. C = Cervical. D = Dorsal.

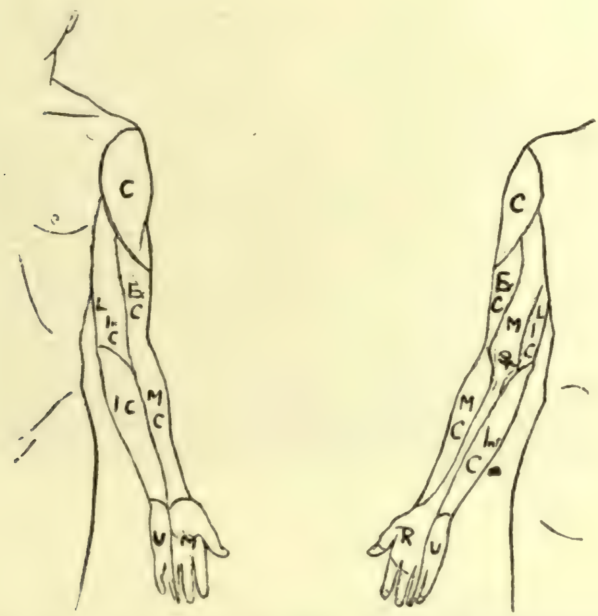


FIG. 34.—Innervation of the skin of the upper limb. Areas of distribution of sensory nerves.

C = Circumflex.
EC = External cutaneous.
MSp = Musculo-spiral.
LIC = Lesser internal cutaneous.
IC = Internal cutaneous.
MC = Musculo-cutaneous.
R = Radial.
M = Median.
U = Ulnar.

ROOT AND TRUNK LESIONS

Lesions of the 5th and 6th Cervical Roots.

Etiology. Lesions of these roots may result from direct injury or from indirect violence applied so as to stretch or rupture the roots by increasing the angle between the shoulder and the head and neck.

Diagnosis. *Motor.*—If the lesions occur near the spinal cord there is paralysis of the rhomboids, serratus magnus, levator anguli scapulæ,

FIG. 35.—Photograph showing upper limit of sensory loss in almost complete lesion of brachial plexus. Anterior.

teres major, supra and infra spinati, clavicular portion of the pectoralis major and of the deltoid, biceps, brachialis anticus, and supinator longus. This results in paralysis of the scapula and dropping of the head of the humerus. The arm hangs limply by the side and cannot be raised or abducted. In addition there is total inability to flex the elbow, as the biceps, brachialis anticus, and supinator longus muscles are paralysed.

In exceptional cases the pronator radii teres and flexors of the wrist may act as flexors of the elbow. Extension of the elbow is not materially affected, and there is but little weakness in the forearm, wrist, and finger movements although the coraco-brachialis, triceps, radial extensors, supinator brevis, pronator radii teres, and other muscles are partly supplied by the 5th and 6th cervical roots. The essential feature from the motor point of view is the paralysis of the shoulder muscles, of the flexors of the elbow, and of the supinators of the forearm.

FIG. 36.—Photograph showing upper limit of sensory loss in almost complete lesion of brachial plexus. Posterior.

Sensory.—The area of sensory loss is variable, but as a rule it will be found to extend along the outer border of the arm, forearm, and hand, from below the middle of the deltoid muscle and including the thumb and index finger. The area of loss to pinprick corresponds closely with that in which there is loss to cotton-wool.

Reflexes.—The biceps and supinator longus tendon reflexes are abolished.

In lesions of the 5th cervical root the paralysis is most marked

FIG. 37.—Diagram of area of sensory loss in lesions of the 5th and 6th cervical roots.

in the deltoid and supinator longus muscles ; although the biceps is also weakened. The area of sensory loss does not extend on to the forearm.

Lesions of the Upper Trunk.

Diagnosis. The signs of lesion of the upper trunk are essentially similar to those resulting from lesions of the 5th and 6th cervical

Figs. 38 and 39.—Photographs of a case of lesion of the 5th cervical root showing area of sensory loss.

roots, differing only in that there is no paralysis of the levator anguli scapulæ, rhomboids, or serratus magnus, as the branches supplying these muscles are given off before the formation of the upper trunk.

Lesions of the 7th Cervical Root and Middle Trunk.

Diagnosis. *Motor.*—The paralysis resulting from a lesion of the 7th cervical root resembles that found in cases of musculo-spiral

FIG. 40.—Photograph of a case of lesion of the 5th cervical root showing area of sensory loss.

paralysis with this important distinction however, that in the former there is no paralysis of the supinator longus muscle which is supplied by fibres coming from the fifth cervical root.

Sensory.—The area of sensory loss found in lesions of the 7th

cervical root is very variable. In two cases of tumour involving the 7th cervical root, an area of sensory loss was found extending in a narrow strip along the middle of the anterior and posterior aspects of the hand and arm, including the contiguous halves of the third and fourth fingers.

Reflexes.—The triceps jerk is abolished.

Lesions of the 8th Cervical and 1st Dorsal Roots and Lower Trunk.

Etiology. The 8th cervical and 1st dorsal roots may be injured by direct or indirect violence. In the latter case the damage to the roots is generally caused by sudden traction applied with great force. The position which throws greatest strain on the lower roots is when the arm is abducted above the horizontal and the angle between the chest and the arm is suddenly widened. Rupture of the lower roots has occurred in cases where a man about to jump from a car or omnibus loses his foothold before he has let go of the rail, with the result that the weight of his body is suddenly thrown on to his arm which is forcibly abducted above his head, while the weight of his body dragging behind extends the angle between his chest and arm. It may also occur as a form of birth palsy in cases of breech presentation where the arm lies over the head and traction is made on the body. In cases of cervical rib, a condition in which there is either a true rib or an unusually large transverse process growing from the seventh cervical vertebra, pressure may be exerted on the nerves passing from the eighth cervical and first dorsal roots, resulting in the gradual development of paralysis and wasting of the small muscles of the hand with tingling and later loss of sensation over the inner border of the forearm and ulnar area of the hand.

Diagnosis. Lesions of the 8th cervical and 1st dorsal roots give rise to the following symptoms :

Motor.—Paralysis and wasting of all the small muscles of the hand and of the flexor carpi ulnaris and inner half of the flexor profundus digitorum.

Sensory.—The area of sensory loss extends along the inner border of the lower part of the upper arm, forearm, and over the ulnar area of the hand.

In addition to the above signs there may be paralysis of the cervical sympathetic on the same side which is recognized by—

(1) A narrowing of the palpebral fissure, resembling a ptosis but differentiated from it by the fact that the eyelid can be raised voluntarily.

(2) A sinking in of the eyeball—enophthalmos.

(3) A contraction of the pupil which does not dilate when shaded from light, when the skin of the neck is pinched, or on placing cocaine solution into the eye.

(4) A diminution of sweating over the neck and face on the same side.

Paralysis of the cervical sympathetic is invariably present when the roots have been torn from the cord.

Lesion of the Lower Trunk.

Diagnosis. The clinical picture is similar to that resulting from lesion of the 8th cervical and 1st dorsal roots, except that there is no affection of the cervical sympathetic.

Lesions of the Outer Cord.

Diagnosis. Lesions of the outer cord are characterized by signs of paralysis of the musculo-cutaneous nerve and outer head of the median nerve.

Motor.—There is paralysis and wasting of the biceps, brachialis anticus, pronators of the forearm and radial flexors of the wrist and fingers. Flexion of the elbow is still possible, this movement being carried out by the action of the supinator longus muscle, but it will be noticed that in the performance of this movement the forearm assumes a position midway between pronation and supination. Flexion of the wrist is possible, the movement being executed chiefly by the flexor carpi ulnaris. Some power of flexion of the fingers is retained, but flexion of the thumb and index finger is very weak. Opposition and abduction of the thumb are not as a rule impaired.

Sensory.—The area of sensory loss extends along the outer border of the forearm and into the median area of the hand. Its extent varies considerably in different cases.

Reflexes.—The biceps tendon reflex is abolished.

Lesions of the Posterior Cord.

Etiology. Lesions limited to the posterior cord may occur as the result of gunshot injuries, but it is much more common to find them associated with lesions of other nerves.

Diagnosis. *Motor.*—Complete lesions of the posterior cord result in paralysis of the musculo-spiral and circumflex nerves, and in addition there is paralysis of the latissimus dorsi, subscapularis, and teres major muscles, as the nerves supplying these muscles arise from the posterior cord.

There is wasting and paralysis of the deltoid, triceps supinator longus, and the extensors of the thumb and fingers.

The patient is unable to abduct the arm or to extend the elbow against resistance. Supination of the forearm is impaired, and there is drop-wrist with inability to extend the wrist, fingers, and thumb.

Sensory.—The area of sensory loss corresponds roughly to that of the circumflex and musculo-spiral nerves. There is loss of sensation over

FIG. 41.—Diagram of area of sensory loss in lesion of the 8th cervical and 1st dorsal roots. (Inner cord.)

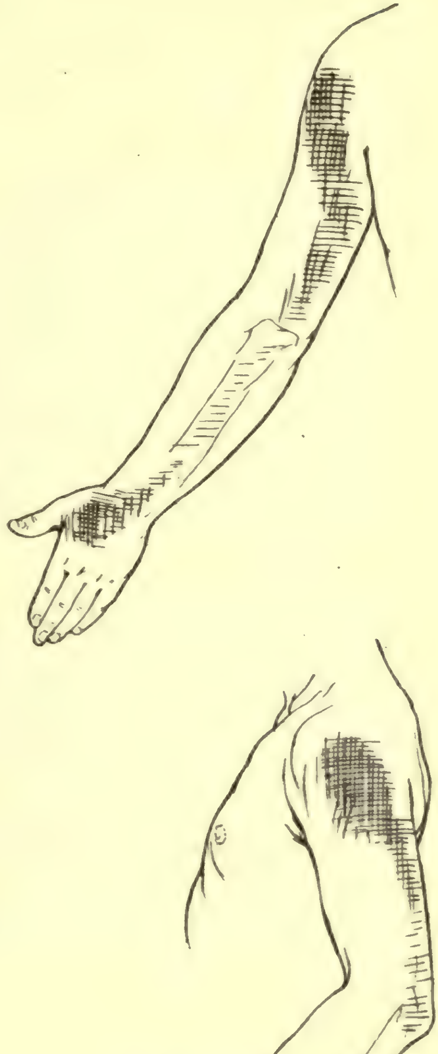
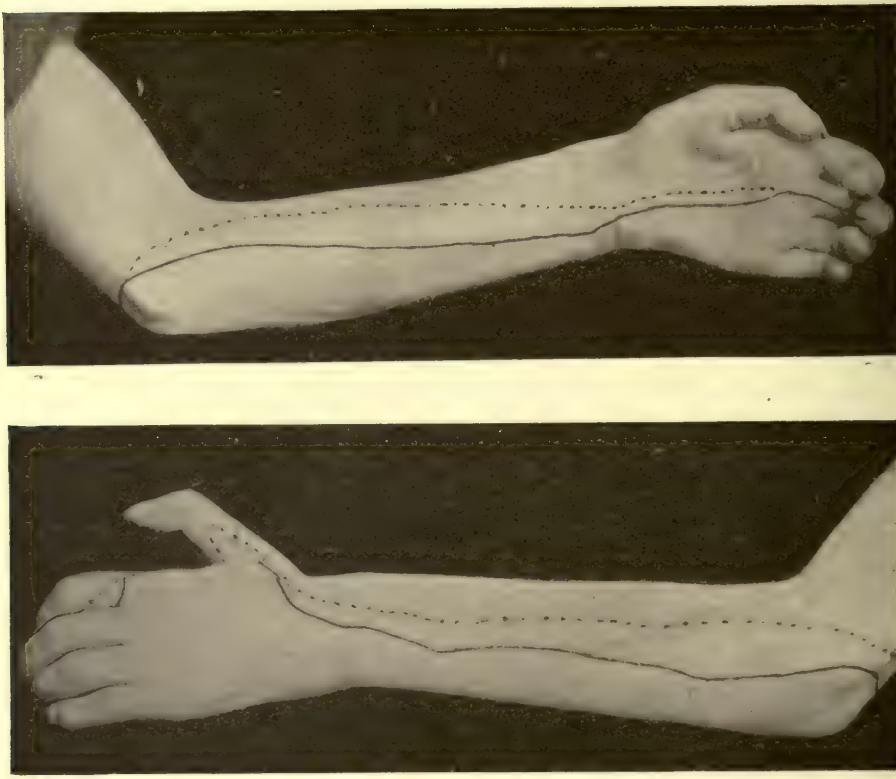


FIG. 42.—Diagram of area of sensory loss in a case of lesion of the posterior cord.

the radial half of the dorsal aspect of the hand, excluding the fingers, extending up to the middle of the dorsal aspect of the forearm and expanding over the dorsal aspect of the upper arm where it spreads round its outer aspect over the prominence of the deltoid muscle.

Reflexes.—The triceps and supinator longus tendon reflexes are abolished.



FIGS. 43 and 44.—Photographs showing area of sensory loss in the forearm and hand in a case of lesion of the posterior and inner cords.

Lesions of the Inner Cord.

Diagnosis. The clinical picture is similar to that seen in lesions of the lower trunk.

Motor.—There is paralysis of the muscles supplied by the ulnar nerve and the inner head of the median, the flexor carpi ulnaris, inner half of flexor profundus digitorum, and all the intrinsic muscles of the hand. There is wasting of the ulnar side of the forearm and of the small hand muscles.

When the wrist is flexed no contraction of the flexor carpi ulnaris will be felt. Opposition and abduction of the thumb are grossly impaired,

and the patient cannot abduct or adduct his fingers if the hand be kept flat on a table.

Sensory.—The area of sensory loss extends over the areas supplied by the ulnar, internal cutaneous, and lesser internal cutaneous nerves, roughly over an area comprising the little finger and ulnar side of the third finger, the corresponding portion of the hand and the inner border of the forearm and upper arm.

COLLATERAL BRANCHES FROM THE BRACHIAL PLEXUS

The Suprascapular Nerve.

Anatomy. This is the most cephalic of the branches of the brachial plexus. It is a considerable nerve derived from the fifth and sixth cervical nerves. Passing behind the plexus it goes through the suprascapular foramen, and is distributed to the supraspinatus and infraspinatus muscles.

Symptoms. There is wasting of the supra and infraspinati muscles. Clinically, paralysis of the supraspinatus alone is unimportant except that the head of the humerus is less firmly fixed. Paralysis of the infraspinatus, if associated with palsy of the deltoid, aggravates the downward displacement of the head of the humerus and impairs the outward rotation of the humerus.

Posterior Thoracic Nerve.

Anatomy. This nerve is formed by the junction of branches from the fifth, sixth, and seventh cervical nerves which takes place in the substance of the scalenus medius muscle. From thence it passes downwards behind the brachial plexus and along the side of the thorax in the mid-axillary line to the lower border of the serratus.

Distribution. It supplies the serratus magnus.

Etiology. It is most commonly injured in the neck—by direct pressure from carrying a heavy, and especially a sharp-cornered, instrument over the shoulder; by blows on the neck and shoulder; by muscular strain, especially repeated and continuous muscular efforts (such as using a heavy hammer), which tend to set up a neuritis from compression of the nerve as it passes through the muscle. It may also be the seat of neuritis, in which case pains in the neck and shoulder usually precede and accompany the onset of the motor weakness.

Diagnosis. The serratus muscle carries the scapula outwards, forwards, and slightly upwards when the arm is advanced. It tends slightly to rotate the scapula on its inner angle. Its chief function is to help in fixing the scapula when the arm is raised above the horizontal in front of the patient.

Motor.—When the muscle is paralysed there may be no obvious

change in the position of the scapula when at rest, but in old-standing cases the unopposed action of the rhomboids may rotate the lower angle slightly inwards. When the arm is moved forward the posterior border of the scapula comes away from the thorax, leaving a deep groove, and at the same time the lower angle of the scapula is rotated inwards and upwards—winged scapula. Elevation of the arm above the shoulder is practically impossible, except for a small amount of movement which is brought about by the contraction of the middle portion of the trapezius muscle.

Differential Diagnosis.—The clinical picture of paralysis of the serratus magnus is so typical that the diagnosis is obvious. The muscle may be paralysed in anterior poliomyelitis, but in that case the history and the involvement of other muscles renders the diagnosis easy. In early cases of myopathy with affection of the shoulder girdle muscles, the serratus may be involved, but the condition is usually bilateral, of very gradual onset, and involves other muscles of the shoulder girdle and frequently the facial muscles.

Circumflex Nerve.

Anatomy. This nerve arises from the posterior cord of the brachial plexus, but its fibres are derived from the fifth and sixth cervical roots.

Distribution. *Motor.*—It supplies the deltoid and the teres minor muscles and sends an articular branch to the shoulder-joint.

Sensory.—It conveys cutaneous sensibility from an area extending, roughly, over the middle and lower portions of the deltoid muscle. The extent and degree of the sensory loss varies considerably in different cases.

Etiology. It may be injured as a result of dislocation of the shoulder, falls on the shoulder, injuries to the neck of the humerus.

Diagnosis. *Motor.*—Paralysis of the deltoid causes inability to raise the arm from the side, although a very slight degree of abduction may be possible owing to the action of the supraspinatus. The wasting of the deltoid muscle causes the shoulder to look flattened and square, and as a rule the head of the humerus falls downwards, so that there is a distinct hollow between the head of the humerus and the acromion.

Sensory.—Along with the motor paralysis some disturbance of cutaneous sensibility will be made out over the deltoid muscle.

TERMINAL BRANCHES FROM THE BRACHIAL PLEXUS

The Musculo-cutaneous Nerve.

Anatomy. The musculo-cutaneous nerve takes origin from the fifth and sixth cervical nerves through the 'outer' cord of the brachial plexus. Incorporated with it is a branch from the seventh cervical nerve, which is destined to supply the coraco-brachialis muscle (Herringham).

The nerve lies at first, with the outer head of the median, external to the axillary artery. Piercing the coraco-brachialis muscle obliquely (the branch to which, enters the muscle before it is pierced by the nerve),

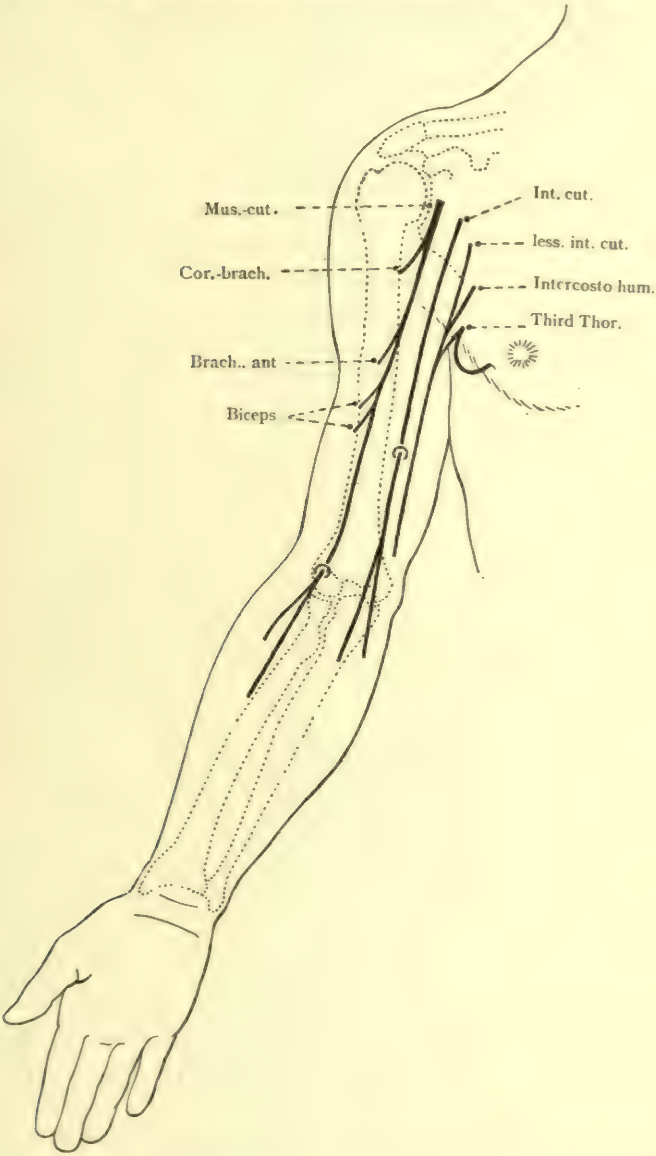


Fig. 45.—Distribution of musculo-cutaneous nerve.

it next lies between the biceps and the brachialis anticus. It supplies branches to each head of the biceps and to the brachialis anticus. It becomes superficial at the bend of the elbow, appearing at the outer border

of the biceps muscles. Passing through the deep fascia it becomes cutaneous, and at once divides into two branches—anterior and posterior. The *anterior branch* supplies the skin of the front of the forearm over its outer half from the elbow to the wrist. The *posterior branch* supplies the skin of the back of the forearm on the outer side, in the upper two-thirds. The musculo-cutaneous often communicates with the median nerve in the arm beneath the biceps. This communication may be from either nerve to the other. In some cases a branch from the musculo-cutaneous is carried down in the median to separate in the lower part of the arm as a nerve to the brachialis anticus. In other cases a branch from the median joins the musculo-cutaneous after the muscular branches have arisen from the latter nerve.

Diagnosis. *Motor.*—There is paralysis and wasting of the coraco-brachialis, biceps and brachialis anticus muscles with weakness of flexion of the forearm and supination of the hand. Strong flexion, however, is still possible if the arm is in the mid-position between pronation and supination, through the action of the supinator longus muscle.

Sensory.—Associated with this paralysis will be found a variable area of cutaneous anæsthesia on the anterior-external and postero-external aspects of the forearm.

In the somewhat rare cases in which the musculo-cutaneous and musculo-spiral nerves are both injured some degree of flexion of the elbow is still possible, through the action of the pronator radii teres and the muscles arising from the inner condyle.

THE MUSCULO-SPIRAL NERVE

Anatomy. The musculo-spiral nerve is derived from the posterior trunks of the anterior primary divisions of the last four cervical nerves. (In some cases it receives a minute filament from the back of the first thoracic nerve.) It forms the continuation of the 'posterior cord' of the plexus into the arm, and is distributed to the back of the arm, forearm, and hand.

The nerve lies at first behind the axillary artery. Proceeding to the arm it is placed, in the upper third, on the inner side of the humerus and behind the brachial artery. In the middle third it winds round the back of the bone in the spiral groove between the triceps and the humerus, accompanied by the superior profunda artery. In the lower third of the arm it is external to the humerus. Piercing the external intermuscular septum, it passes downwards, lying deeply between the brachio-radialis (supinator longus) and brachialis anticus muscles. It terminates in front of the external condyle of the humerus by dividing into the radial and posterior interosseous nerves.

Collateral Branches of the Musculo-spiral Nerve.

The musculo-spiral nerve gives off the following branches in its course down the arm :

(*a*) Three branches arising on the inner side of the arm—

(1) A muscular branch to the long head of the triceps ;

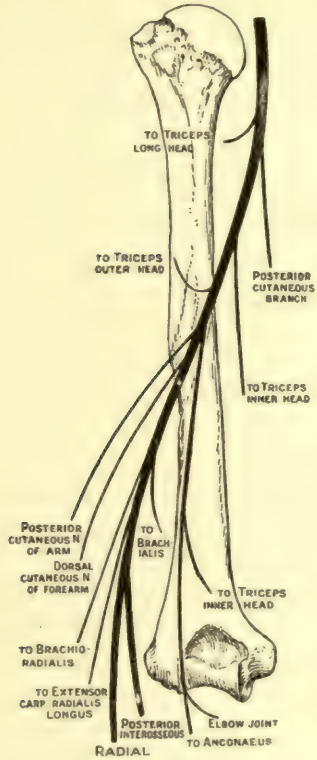


FIG. 46.—Scheme of the musculo-spiral nerve.

(2) An internal cutaneous branch, distributed to the skin of the arm behind the area supplied by the intercosto-humeral nerve ;

(3) A muscular branch to the inner head of the triceps. This branch accompanies the ulnar nerve in part of its course, and is known as the ulnar collateral.

(*b*) During its passage along the muscular spiral groove and back of the arm, the nerve gives off—

(1) A muscular branch to the outer head of the triceps ;

(2) A muscular branch to the inner head of the triceps (and anconeus), which also supplies the elbow-joint ;

(3) Two external cutaneous branches—*superior*, which is the smaller and supplies the skin over the lower half of the back of the arm, and the back of the elbow-joint ; and, *inferior*, the larger, which supplies the skin of the back of the arm in its lower third and the skin of the back of the forearm being wider above and tapering below in a strip down the middle of the back of the forearm.

(*c*) Three branches which arise on the outer side of the arm for the supply of the (supinator longus) brachio-radialis, extensor carpi radialis longior, and brachialis anticus. The nerve to the last-named muscle may not be present, as its main nerve supply is derived from the musculo-cutaneous nerve.

Terminal Branches of the Musculo-spiral Nerve.

The Radial Nerve. The radial nerve proceeds down the front of the forearm on its outer side under cover of the supinator longus muscle. It meets with the radial artery at the junction of the upper and middle thirds of the forearm, lying on the outer side of the artery, in the middle third of the forearm. At the junction of the middle and lower thirds of the forearm it passes obliquely downwards and backwards beneath the tendon of the supinator longus and becomes cutaneous on the back of the forearm.

It is a purely cutaneous nerve and is distributed to the back of the lower third of the forearm and the back of the hand and fingers in a somewhat variable way. It supplies the dorsum of the thumb, except over the distal phalanx, the lower part of the proximal phalanx of the middle and ring fingers, the dorsal surface of the web between the thumb and index finger and an area extending upwards over the dorsum of the hand and on to the back of the forearm.

In all cases the area of sensory loss, which can be demonstrated after division of the nerve, is much smaller, and may only extend over a triangular patch between the base of the thumb and the base of the index finger.

The Posterior Interosseous Nerve. The posterior interosseous nerve passes downwards over the front of the external condyle and on the outer side of the forearm under cover of the supinator longus muscle. It sweeps round the shaft of the radius and appears on the back of the forearm in the upper third. Lying on the back of the forearm at first beneath the origin of the superficial extensor muscles of the forearm, it lies successively on the supinator brevis and extensor ossis metacarpi pollicis. Then, passing beneath the extensor longus pollicis, it continues its course on the interosseous membrane. It ends finally by supplying the radio-carpal and intercarpal joints. In the middle third of the back of the forearm the nerve is accompanied by the posterior interosseous artery.

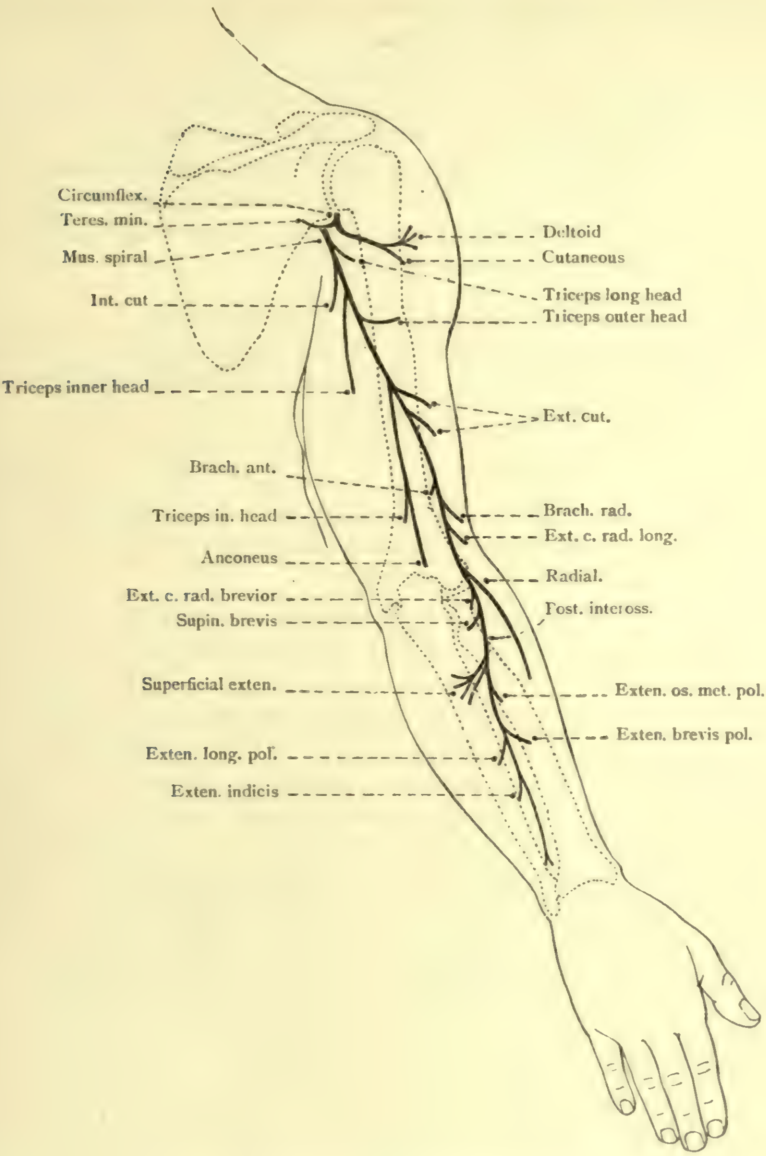


FIG. 47.—Scheme of the musculo-spiral nerve.

The branches given off by the posterior interosseous nerve are as follows :

Before piercing the supinator brevis it supplies branches to the extensor carpi radialis brevior and supinator brevis. Immediately after appearing on the back of the forearm the nerve supplies a bundle of branches for the extensor communis digitorum, extensor minimi digiti, and extensor carpi ulnaris. Proceeding downwards the nerve supplies branches to the extensor ossis metacarpi pollicis, extensor longus pollicis, extensor brevis pollicis, and extensor indicis.

Lesions of the Musculo-spiral Nerve.

Etiology. The musculo-spiral nerve runs a long course and by reason of its position and relationship to the humerus, it is paralysed more often than any of the other nerves of the arm.

It is the extensor nerve of the arm, and as such, has a more or less definite function in that it supplies the muscles which extend the elbow, wrist, fingers, and thumb. This explains why paralysis of the musculo-spiral nerve may be simulated by functional paralysis in which movements or groups of movement are affected.

Lesions of the musculo-spiral nerve may arise from direct injury, or may result from dislocation of the shoulder, from pressure exerted on the nerve as in ' crutch ' palsy or ' Saturday night ' paralysis. The nerve may be involved in any part of its course and the symptoms resulting will depend upon the level of the lesion. Apart from injury it may be the seat of neuritis.

Diagnosis.—The clinical picture of a complete musculo-spiral paralysis is characterized by inability to extend the elbow and the presence of drop-wrist and drop-fingers with inability to extend the wrist, fingers or thumb. In total lesions the tone of the muscles is abolished and the hand droops helplessly, and in a short time, unless steps are taken to prevent it, the dorsum of the wrist becomes prominent, the back of the hand appears to be narrowed, and the thumb becomes adducted owing to the unopposed action of the adductores pollicis.

(1) *High Lesion at the Lower Part of the Axilla.*

Motor.—There is complete paralysis of the triceps, anconeus supinator longus and brevis, extensor carpi radialis longior and brevior, extensor longus digitorum, extensor minimi digiti, extensor carpi ulnaris, extensor ossis metacarpi pollicis, extensor brevis pollicis, and extensor indicis.

Sensory.—There is loss of sensation over an area on the dorsal surface of the hand, extending from between the dorsal aspect of the thumb and the base of the index finger, upwards towards the middle of the wrist. in this area the extent of actual loss of sensation may vary, but almost invariably the patient complains of a fairly wide area of numbness in this region. Loss of sensation on the dorsal surface of the elbow and back

of the upper arm may also be detected by careful examination in some cases, but here again the area of subjective disturbance may greatly exceed the area of definite loss.

It is rare to find a patient complaining of pain in cases of musculo-spiral paralysis, even in cases where the motor and trophic disturbances suggest an irritative lesion. If pain is present it is usually located in the region of the elbow.

Reflexes.—The triceps and supinator longus reflexes are abolished.

(2) *Lesions at a slightly Lower Level below the Points of Origin of the Branches which Supply the Inner and Long Heads of the Triceps.*

In these cases only the outer head of the triceps and the anconeus are paralysed, and the triceps tendon reflex is present but the supinator longus reflex is abolished.

(3) *Lesions above the Origin of the Branch to the Supinator Longus Muscle,* which is given off about the level of the middle and lower thirds of the arm.

Motor.—This is the commonest seat of injury. Lesions at this level are characterized by the escape of the triceps and anconeus, with ability to extend the elbow and retention of the triceps tendon reflex. The supinator longus and all the extensor muscles of the wrist, fingers, and thumb are paralysed. The elbow can be flexed by the biceps and brachialis anticus, but if the other arm be tested as a control, the difference on the two sides will be obvious. The supinator longus muscle will stand out in strong contraction on the normal side, whilst on the affected side the paralysed muscle remains inactive.

All extensor action of the wrist, fingers, and thumb is absent.

Sensory.—An area of numbness and sensory loss is present over the back of the thumb and in the region of the first interosseous space on its dorsal aspect.

Reflexes.—The triceps reflex is present but the supinator reflex is absent.

(4) *Lesions below the Origin of the Branch of the Supinator Longus and Extensor Carpi Radialis Longior.* (At the level of the epicondyle.)

Motor.—There is paralysis of the extensor carpi radialis brevior and of the extensors of the fingers and thumb.

Sensory.—Sensory loss is present over the back of the thumb and first interosseus space.

Reflexes.—The triceps and supinator longus tendon reflexes are retained.

FIG. 48.—Flexion of the elbow in a normal person, the forearm being in the mid-position. Note contraction of supinator longus.

FIG. 49.—Flexion of the elbow in a case of musculo-spiral paralysis, the forearm being in the mid-position. Note (*a*) absence of contraction of supinator longus muscle; (*b*) area of sensory loss within continuous line, loss to pinprick within dotted line, loss to cotton-wool. Patched area indefinite sensory loss with subjective feeling of numbness.

(5) *Lesions below the Level at which Branches to the Radial Extensors are given off.*

Motor.—Lesions at this level cause paralysis of the extensor carpi ulnaris and the extensors of the fingers, but the wrist can still be extended by the radial extensors and will at the same time be deviated to the radial side. All the extensor muscles of the fingers may be paralysed, but as the nerves to the extensor communis arise separately paralysis of one or more fingers only may be noted.

Sensory.—As the nerve radial is given off above this level there will be no cutaneous sensory loss.

(6) *Lesions at a Level below the Middle of the Forearm.*

This may result only in paralysis of the extensor muscles of the thumb and index finger.

SUMMARY

Paralysis of the extensor muscles results in wrist-drop and loss of power to extend the wrist and proximal phalanges of the fingers and thumb. The patient, however, is able to keep the fingers extended at the interphalangeal joints as the muscles which actuate this movement—interossei and lumbricales—are supplied by the ulnar nerve. In early and slight cases the droop of the wrist may not be marked, but in severe cases, with loss of tone in the paralysed muscles, the wrist-drop is obvious and a prominence is noted on the dorsum of the carpus. This may sometimes be due to swelling of the synovial sheaths round the extensor tendons, but is often due to a definite alteration in the bony structures—the carpus becoming narrowed and projecting backwards. The drooping of the fingers is often most marked in the fourth finger, being least pronounced in the first. Flexion of the fingers is weakened, not because of weakness of the flexor muscles, but on account of the paralysis of the extensors, which normally hold the wrist in a position of extension and provide the flexor muscles with a fulcrum on which to act. In mild degrees of extensor weakness, if the patient is asked to grasp an object firmly, the wrist will be seen to flex, and the forearm becomes pronated. This pronation is a serious inconvenience as it renders it difficult for the patient to raise a cup to his lips without spilling it.

In complete lesions hypotonia and muscular wasting become extreme. In irritative lesions there is usually little or no cutaneous pain, but a very considerable degree of nerve and muscle tenderness. Swelling of the synovial sheaths, adhesions, and contractions of the muscles and tendons may occur, and these may be so severe as to prevent the occurrence of drop-wrist, and even to hinder flexion of the wrist and fingers. Vaso-motor symptoms are rarely met with.

Differential Diagnosis.

From Lead Paralysis.—In cases of lead paralysis a condition of drop-wrist may develop, but the gradual onset of the paralysis, the history of prolonged exposure to lead, and the evidence of lead intoxication in the presence of a blue line on the gums together with anæmia and a history

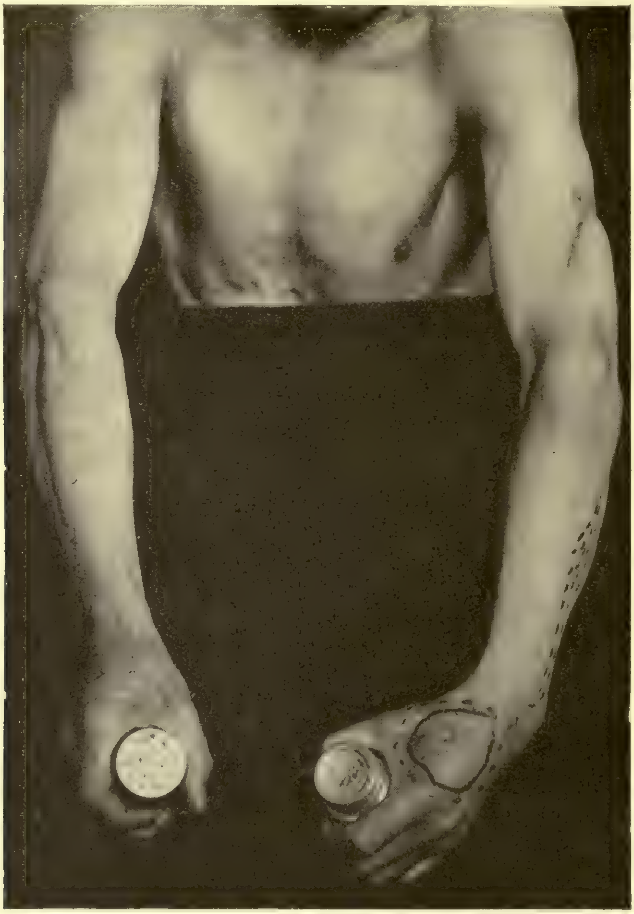


FIG. 50.—Illustrating flexion and pronation of the wrist in a case of musculo-spiral paralysis when grasping an object tightly. Right hand normal, left hand musculo-spiral paralysis.

of constipation and colic, should suffice to distinguish drop-wrist, due to lead, from a musculo-spiral paralysis due to injury. In cases of lead paralysis the supinator longus muscle usually escapes and there is no sensory disturbance.

From Peripheral Neuritis.—In peripheral neuritis due to alcohol or

arsenic, pain is a prominent feature with tenderness on pressure over the muscles and nerves, and sensory disturbances are present all over the fingers and hand. The gradual onset, the character of the paralysis, and a history of exposure to arsenic or to the effects of alcohol, will suffice to render the diagnosis easy.

From Functional Paralysis.—Functional drop-wrist is not uncommon, but is easily distinguished from organic paralysis, as the supinator longus action is preserved and in grasping there is no flexion of the wrist. The deep reflexes are retained, and if sensory loss be present it is not confined to the radial distribution but is generally of the 'glove' type extending up to a definite level. Finally, electrical testing will confirm the diagnosis, as in functional paralysis the faradic response will be normal.

From Injury to the Extensor Muscles and Tendons.—In cases where muscles or tendons on the extensor surface have been injured or divided, it may be difficult to decide whether the drop-wrist is due to a nerve lesion or to division of the muscles and tendons. A knowledge of anatomy and electrical testing will, however, solve the question.

From Paralysis due to Prolonged Splinting of the Hand in a Flexed Position.—In certain cases where the hand has been splinted in a position of flexion, voluntary power of extension may be lost, but in these cases there is no sensory loss and the electrical responses are normal.

THE MEDIAN NERVE

Anatomy. The median nerve takes origin by two heads, an outer head derived from the sixth and seventh cervical nerves through the 'outer' cord, and an inner head derived from the eighth cervical and first thoracic nerves through the 'inner' cord. The outer head is placed external to the axillary artery; the inner head crosses over the vessel obliquely. Thus formed, the nerve passes down through the upper arm in close relation to the brachial artery. In the upper half of the arm it is external to the artery. In the lower half it crosses over the artery obliquely, so as to be ultimately on its inner side.

It proceeds straight down the middle of the forearm, lying deeply in its whole course. It first passes between the two heads of the pronator radii teres, separated at this stage from the ulnar artery by the deep head of the muscle. Thereafter it proceeds downwards between the flexor sublimis digitorum and the deep muscles of the forearm to the wrist. In the lower fourth of the forearm the nerve is situated immediately behind the tendon of the palmaris longus muscle, external to the tendons of the flexor sublimis digitorum.

In the forearm it is accompanied by an artery of variable size—the comes nervi mediani. At the wrist it passes beneath the anterior annular

ligament, enveloped by the synovial sheath which surrounds the flexor tendons. Reaching the palm of the hand it separates into its terminal branches for the supply of the skin of the fingers and thumb, and of certain muscles of the thumb.

Branches of the Median Nerve.

A. *In the Arm.*—The median nerve gives off no branches in the arm except the occasional communication with the musculo-cutaneous nerve already mentioned.

B. *In the Forearm.*—(1) *Muscular Branches.*—The median nerve supplies in the upper part of the forearm the following muscles : pronator radii teres, flexor carpi radialis, palmaris longus, and flexor sublimis digitorum. A second branch to the flexor sublimis digitorum is given off in the middle third of the forearm.

Anterior Interosseus Nerve.—This nerve arises from the median in the upper third of the forearm, and courses downwards on the interosseus membrane between the flexor longus pollicis and flexor profundus digitorum, accompanied by the anterior interosseus artery. It supplies these muscles, and terminates by entering the posterior surface of the pronator quadratus. It also supplies twigs to the wrist-joint.

(2) *A Palmar Cutaneous Branch.*—This branch arises in the lower third of the forearm and, piercing the fascia above the anterior annular ligament, supplies the skin of the palm of the hand.

(3) A contribution from the ulnar to the median nerve is frequently given off in the forearm, reinforcing the branches of the latter nerve to parts of the flexor sublimis digitorum. Thus after division of the median nerve there may still be retained power of movement in these digits.

C. *In the Hand.*—(1) *Muscular Branch.*—Immediately below the lower border of the anterior annular ligament, a short muscular trunk is given off, which is directed outwards superficially to the muscles of the thumb. It supplies the abductor, opponens, and flexor brevis pollicis.

(2) *Terminal Branches.*—The terminal branches of the nerve are five twigs, which pass downwards between the palmar arch and the long flexor tendons to supply each side of the thumb, the radial side of the index finger and the first lumbrical muscle, the adjacent sides of the index and middle fingers and the second lumbrical muscle, and the adjacent sides of the middle and ring fingers.

The cutaneous branches to the index, middle, and ring fingers supply branches which are distributed also to the dorsal aspects of these fingers.

Lesions of the Median Nerve.

Diagnosis. *General Appearance.*—In cases of complete paralysis of the median nerve, the hand may be slightly deviated towards the ulnar

side. The thenar eminence is wasted and the outer border of the ball of the thumb is flattened and hollowed out. The position of the thumb

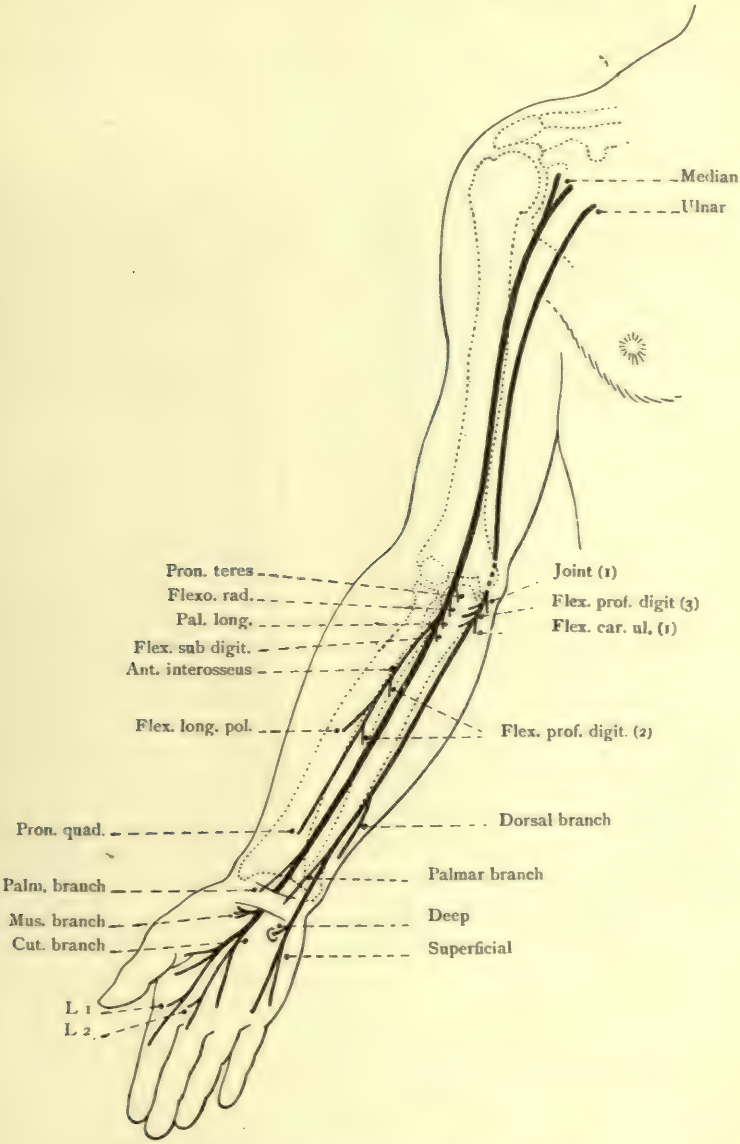


FIG. 51.—Distribution of the median and ulnar nerves.

is altered, in that it is held extended and closely adducted to the hand, and instead of lying on a plane anterior to that of the fingers, it tends to fall back to the same plane.

Vaso-motor and Trophic Changes.—As a rule vaso-motor and trophic changes in the skin are more pronounced than in the case of ulnar paralysis, and especially in cases of nerve irritation or when the nerve injury is complicated by a vascular lesion, as is not infrequent. The greatest change is seen in the two terminal phalanges of the index and middle fingers which may be blue and cold. Over the whole of the median area the skin may be atrophied, whilst in other cases horny desquamation may be present over the outer side of the palm. In cases of nerve irritation there is excessive sweating and the nails are curved, narrowed, frayed or fissured, having an opaque appearance, and between the ends of the nails and the points of the fingers there is often a collection of white skin which is excessively tender to touch.

Motor Changes.—In complete lesions of the nerve there is (1) inability to pronate the forearm beyond the mid-position between supination and pronation, movement up to this point being brought about by the supinator longus. (2) Flexion of the wrist is impaired, the movement being carried out by the flexor carpi ulnaris (ulnar nerve) without any contraction of the flexor carpi radialis, flexor sublimus, or palmaris longus muscles. (3) The thumb remains in a position of extension and adduction and cannot be opposed to the tips of the fingers. The thumb can be drawn across the palm by the action of the adductors, but in this movement it is the inner side of the pad of the thumb which is brought into contact with the finger. In some cases the action of the opponens is closely simulated by the combined action of the extensor ossis metacarpi pollicis and the adductor muscles, innervated respectively by the musculo-spiral and ulnar nerves. (4) Abduction of the thumb is abolished, that is to say that when the hand is lying flat palm uppermost, the thumb cannot be raised from the palm in the true vertical plane. (5) The distal phalanges of the thumb and index finger cannot be flexed and that of the middle finger but feebly. All the fingers can be flexed at the metacarpo-phalangeal joints and extended at the inter-phalangeal. Slight power of flexion of the terminal phalanx of the thumb is often demonstrable. This action is accomplished by extension of the thumb (musculo-spiral), which causes the paralysed flexor longus pollicis tendon to act mechanically as a ligament.

Sensory Changes.—Pain is such a common symptom in cases of lesion of the median nerve that some authors describe lesions of the median nerve under two headings—painless and painful. It will suffice, however, if we place in the category of painful lesions (1) cases of nerve irritation, (2) cases complicated with vascular disturbances, and (3) cases which fall into the group described by Weir Mitchell as 'Causalgia'. These cases are characterized by the absence of severe motor paralysis, by the

development of a peculiar condition of the skin which is atrophied and of a glossy pinkish-blue colour, and by the invariable occurrence of agonizing burning pain, spontaneous in origin and spread over the distribution of the nerve. This pain is aggravated by heat, exposure to the air, the dependent position, jars, or emotional disturbances.

In these cases there is generally a cutaneous hyperalgesia with hypoæsthesia, and often preservation of normal deep sensibility.

. 52.—Photo showing extreme area of nsory loss in a case of median paralysis.

FIG. 53.—Photo showing extreme area of sensory loss in a case of median paralysis.

In cases where the nerve has been completely divided, it is rare to find the patient complaining of pain in the distribution of the nerve.

The area of cutaneous sensory loss in an extreme case is illustrated by the accompanying photographs. It extends over the palmar surface of the thumb, index, and middle fingers, and the radial half of the ring finger and the corresponding portion of the palm to the wrist. On the dorsal surface the area includes the back of the terminal phalanx of the thumb and of the second and third phalanges and half of the first phalanges of

the index and middle fingers and corresponding radial area on the ring finger.

The area of loss to pinprick is distinctly less than that to cotton-wool and is constant only on the index finger and thumb, extending down-

FIGS. 54–57 show more typically the areas of sensory loss in cases of median paralysis.

FIG. 54.

FIG. 55.

wards on to the palm and on the dorsal surface over the distal or middle phalanges. If the nerve is divided in the arm deep sensibility is lost in the index finger and ball of the thumb, and joint sense is lost in the two interphalangeal joints of the index finger and the distal interphalangeal joint of the middle finger.

In lesions below the lower third of the forearm the palmar cutaneous branch may escape and the sensory loss is then confined to the thumb and fingers.

Lesions of the Median Nerve in the Forearm.

(1) *Injuries near the Elbow.*—These may result in (*a*) partial paralysis of the pronator radii teres, flexor carpi radialis, and palmaris longus

muscles, with complete paralysis of the flexors and small muscles of the hand supplied by the median nerve, and, (*b*) sensory loss over the same area. This is due to the fact that the branches innervating the pronator radii teres, flexor carpi radialis, and palmaris longus arise from the nerve at a higher level than those supplying the flexor muscles.

Fig. 56.

Fig. 57.

(2) *Injuries between the Lower and Upper Thirds of the Forearm.*—These injuries may or may not paralyse the flexors, but the sensory changes are spread over the whole of the median area.

(3) *Injuries in the Lower Third of the Forearm.*—In these cases the small thumb muscles are paralysed, but the flexors escape and the sensory loss is limited to the terminal areas of the thumb and fingers.

Partial Lesions of the Median Nerve.

There is good reason to believe that the fibres destined for the different muscles supplied by the nerve are grouped together, and thus partial

lesions may result in the escape of some fibres and destruction of others, with resulting dissociated paralysis. The exact relationship of these groups, however, has not yet been definitely determined.

FIG. 58.—Diagram showing the smallest area of sensory loss known to occur in a lesion of the median nerve below the middle third of the forearm.

THE ULNAR NERVE

Anatomy. The ulnar nerve takes origin through the ' inner ' cord of the plexus, from the eighth cervical and first thoracic nerves.

In the axilla it lies on the inner side of the axillary artery, with the other nerves derived from the ' inner ' cord.

In the arm the nerve courses downwards on the inner side of the brachial vessels. At the middle of the arm it recedes from the artery and passing over the internal intermuscular septum, it continues its course behind the septum and in front of the triceps muscle to the elbow.

After passing behind the internal condyle of the humerus, it enters the forearm between the two heads of the flexor carpi ulnaris. In the forearm the nerve passes down between the flexor carpi ulnaris and flexor profundus digitorum to the wrist. It joins the ulnar artery in the middle third of its course, and continues downwards on its inner side.

At the wrist, just above the anterior annular ligament, the ulnar nerve and artery pierce the deep fascia, and lie on the anterior annular ligament external to the pisiform bone. They are protected in this situation by a strong band of fascia, which passes from the pisiform bone to the annular ligament.

The nerve divides below the ligament into its terminal branches—superficial and deep—for the supply of the skin and muscles of the hand.

The ulnar nerve gives off no branches in the arm.

At the elbow it supplies an articular branch to the elbow-joint.

Muscular Branches of the Ulnar Nerve.

In the forearm, just below the elbow, two muscular branches arise to supply the flexor carpi ulnaris and the inner half of the flexor profundus digitorum muscles.

Cutaneous Branches. Two cutaneous branches arise in the forearm.

The Dorsal Branch.—The dorsal branch is given off in the middle third, and, passing downwards and backwards behind the flexor carpi ulnaris, it becomes cutaneous in the lower third of the back of the forearm. Passing over the posterior annular ligament the nerve is distributed on the back of the hand and fingers, supplying the back of the little finger in its whole length, and the inner half of the ring finger. It supplies in some cases the whole of the back of the ring finger. It communicates with the radial nerve on the back of the hand.

The Palmar Branch.—The palmar branch is a minute filament which arises from the ulnar nerve in the lower third of the forearm. It supplies the palm of the hand after passing through the deep fascia and over the anterior annular ligament. It communicates with the palmar branch of the median nerve.

There is frequently a contribution from the ulnar to the median nerve in the forearm.

Terminal Branches. The ulnar nerve divides in the palm into its terminal branches, superficial and deep.

The Superficial Branch.—The superficial branch supplies twigs to the palmaris brevis muscle and to the skin of the inner part of the palm, and ends by dividing into two digital branches, inner and outer, supplying respectively the inner side of the little finger and the adjacent sides of the little and ring fingers.

The Deep Branch.—The deep branch passes through the origins of the muscles of the little finger, and is situated along with the deep palmar arch upon the interosseus muscles. It supplies the following muscles: the inner two lumbrical muscles, the abductor, opponens and flexor brevis minimi digiti, all the palmar and dorsal interosseus muscles, the adductor pollicis, and interosseus primus volaris. (See Fig. 51, p. 95.)

Lesions of the Ulnar Nerve.

Etiology. Apart from direct injury to the nerve by gunshot wounds, contusion or division of the nerve, ulnar paralysis may develop gradually as a result of prolonged irritation of the nerve from pressure which causes a thickening of the nerve sheath and subsequent compression of the nerve. This usually takes place at the elbow and may be associated with an old injury or with the performance of special movements by patients in whom the relationship of the nerve to the condyle is abnormal. A more acute form of the same condition may arise in patients who as the result of illness or operation are confined to bed. An interesting example of this type was that of a patient who was in the habit of lying and sleeping with his fingers interlocked behind his head, gradually developed bilateral ulnar paralysis, the first symptoms being tingling in the ulnar areas followed by weakness and wasting of the ulnar muscles. Recovery ultimately took place when means were adopted to prevent him from placing his hands behind his head.

Diagnosis and Signs of Lesions of the Ulnar Nerve.

General Appearance of the Limb.—There is atrophy of the hypothenar eminence, of the adductors of the thumb and of the interossei and ulnar lumbricales, and the inner side of the forearm is wasted. The atrophy of the interossei may be extreme, especially in the first interosseus space, and this gives the back of the hand a skeleton-like appearance. The hand may deviate slightly to the radial side. The position of the hand is characteristic. When at rest, the little finger remains in a position of hyperextension at the metacarpo-phalangeal joint and is usually slightly abducted, and there is a variable degree of flexion at the interphalangeal joints. The ring finger is also extended at the metacarpo-phalangeal joint and flexed at the interphalangeal joints but to a lesser degree. This position is known as 'claw hand' or 'ulnar griffe'. It is present in cases of high lesions of the ulnar nerve—that is lesions above the level of the origin of the branches which supply the flexor carpi ulnaris and flexor profundus digitorum muscles, but is always more pronounced in lesions below that level and is found in its most extreme form in cases when the lesion is an irritative one.

Motor.—On testing voluntary movement, if the lesion be at or above the elbow—(1) flexion of the wrist is possible, being carried out by the

median flexors, but no contraction of the flexor carpi ulnaris will be felt and the hand may be deviated to the radial side. (2) Simultaneous flexion of the fingers at the metacarpal phalangeal joints and extension at the interphalangeal joints is impossible owing to the paralysis of the interossei and inner lumbricales. (3) If the hand be placed and kept

Fig. 59. Fig. 60.

Photographs showing the position of the fingers and the area of sensory loss in a case of ulnar paralysis.

horizontally upon a table, the fingers cannot be spread out in a fan-like fashion ; this movement, however, is possible if the patient be allowed to use his extensors, but it will be noted that in so doing the fingers are raised from the table. (4) Adduction of the thumb is impaired owing to the paralysis of the adductor muscles, but the movement of adduction can be simulated by the combined action of the extensors and median intrinsics

of the thumb. In contrast to the weakness of adduction of the thumb is the unimpaired action of opposition which is carried out by the opponens pollicis (median nerve).

In lesions below the origin of the branches to the flexor carpi ulnaris and inner half of the flexor profundus, the motor paralysis is confined to the small ulnar hand muscles.

Vasomotor and Trophic Changes.—Vasomotor changes are less striking than in cases of median paralysis. The ulnar area may be cold and cyanosed, but usually little change is noticed except in cold weather. In irritative lesions redness and sweating may be present and associated with trophic changes in the nails of the little and ring fingers. Trophic changes in the skin are generally slight, although in old-standing cases horny desquamation on the palmar surface is sometimes present. Accidental sores due to burns, &c., may develop in the anæsthetic area.

Sensory Changes.—The area of loss of *cutaneous sensibility* extends over the little finger and ulnar half of the ring finger and over the corresponding portion of the hand on its palmar and dorsal surfaces as high up as the wrist. There is, however, a considerable degree of variation in some cases, more especially as regards the area supplied on the ring finger. It must not be forgotten that even in cases of complete division of the nerve at a high level the area of loss to pinprick may be confined to the terminal phalanx of the little finger and the ulnar half of the proximal phalanges and inner border of the distal portion of the hand (see diagram, Fig. 61). Such a small area of loss to pinprick might lead one to think that the lesion was incomplete or that recovery was taking place, but unless there is definite evidence of recovery the discovery of a small area of loss to pinprick should not be interpreted as necessarily implying commencing recovery.

In lesions below the origin of the dorsal cutaneous branch, which is given off in the middle third of the forearm, the sensory loss is confined to the palmar surface, extending over the distal phalanges.

In lesions below the wrist the superficial palmar branches may escape, in which case there is no cutaneous sensory loss in the palm.

Deep Sensibility.—*Vibration* sense is lost in the little finger and ulnar side of the hand, and sometimes along the ulnar side of the ring finger.

Joint sense is abolished in the little finger but retained in the ring finger.

Pressure sense is lost in the little finger and along the ulnar border of the hand.

In contrast with lesions of the median nerve, the occurrence of spontaneous pain in injuries to the ulnar is extremely rare, and in our experience is generally associated with irritative lesions. On the other

hand, in cases of lesion of both the median and ulnar nerves, spontaneous pain may be referred to spots within the ulnar area.

Recovery.—Restoration of sensation precedes the return of motor power although complete recovery of sensation rarely, if ever, takes place before the return of some voluntary power. The motor recovery is first noted in the flexor carpi ulnaris and flexor profundus digitorum,

FIG. 61.—Diagram showing the smallest area of sensory loss observed by us in a case of complete division of the ulnar nerve at a high level.

and these muscles may be acting voluntarily before sensation is restored. Owing to the small size of the interossei, individual treatment is necessary in order to prevent the occurrence of irreparable atrophy and fibrotic changes.

Differential Diagnosis.—Ulnar paralysis may be simulated by lesions of the inner cord or lower trunk of the brachial plexus, or of the eighth cervical and first dorsal roots, or in cases of cervical rib ; but in all of

these there is wasting and paralysis of all the small muscles of the hand, median as well as ulnar, and the area of sensory loss extends up the inner side of the forearm. In addition, in cases of root lesions, signs of involvement of the cervical sympathetic may be present. It may happen that in syringo-myelia the earliest manifestations resemble those of ulnar paralysis, but as a rule in this disease the signs are bilateral and involve

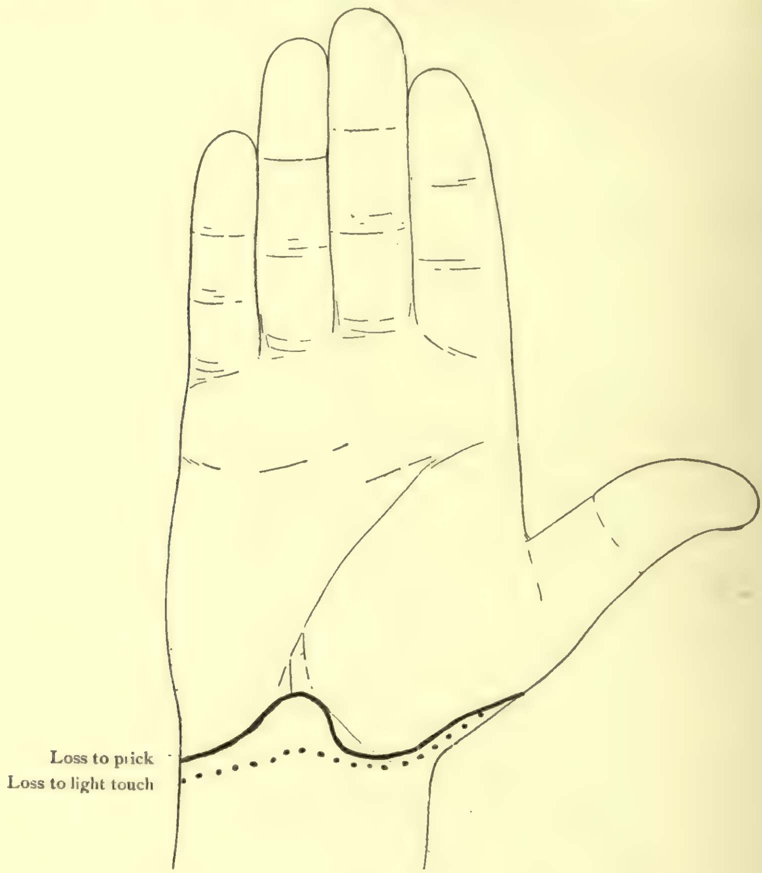


FIG. 62.—Diagram of area of sensory loss in a case of median and ulnar paralysis.

the median and ulnar intrinsics and the sensory changes present show typical dissociated sensory loss to heat, cold, or pain with preservation of light touch. Evidence of involvement of the conducting tracts in the spinal cord will confirm the central origin of the symptoms.

Progressive muscular atrophy will not be confused with ulnar paralysis owing to the absence of all sensory symptoms and the presence of fibrilla-

tion in the wasting muscles together with the bilateral spread of the disease and involvement of the pyramidal tracts.

Combined Paralysis of Median and Ulnar Nerves.

Etiology. Combined paralysis of the median and ulnar nerves may result from injuries in the upper arm or forearm.

FIG. 63.—Diagram of area of sensory loss in a case of median and ulnar paralysis.

Diagnosis. *Motor.*—When the lesion occurs in the upper arm there is complete paralysis of pronation of the forearm from the mid position and of flexion of the wrist and fingers. All the thenar and hypothenar muscles are paralysed and there is marked wasting of the palm, thenar, and hypothenar eminences, and the hand appears flat. The thumb tends to fall back to the same plane as the fingers and there is no power to adduct the fingers, and the thumb cannot be adducted or opposed. Slight

abduction of the fingers and the thumb are brought about by extension of the wrist and fingers, but if the hand be kept flat on a table with the palm downwards no abduction takes place. The extensors of the thumb and fingers are not paralysed and the hand assumes an attitude in which there is hyperextension of the first phalanges and this brings about slight flexion of the second and third phalanges, owing to

FIG. 64.

FIG. 65.

Photographs showing the hand in a case of paralysis of the median and ulnar nerves.

the paralysis of the interossei. Although flexion of the wrist by the flexor muscles is abolished, some flexion may take place at the wrist by the action of the extensor ossis metacarpi pollicis. Flexion of the fingers is induced mechanically by extending the wrist by the radial extensors.

In recovering cases a four-fingered griffe is produced when tone returns to the flexor muscles and flexor tendons, which causes flexion of the two distal phalanges because of the paralysis of the interossei,

which are antagonistic in that they extend the two distal phalanges. This griffe is easily reducible.

In irritative lesions of the median and ulnar, a severe form of neuritic griffe develops with fibrous contraction of the muscles and tendons which may prevent any extensor action at all.

FIG. 66.—Photograph showing in contrast with Fig. 65 the area of sensory loss in a case of paralysis of the ulnar and radial nerves.

Sensory.—The sensory changes in associated median and ulnar paralysis are usually very complete over the whole of the anterior surface of the fingers, and over the fourth and fifth fingers and distal portions of the ring and index fingers and the thumb.

In irritative lesions, especially when the median nerve is affected, there is severe pain in the distribution of the nerve.

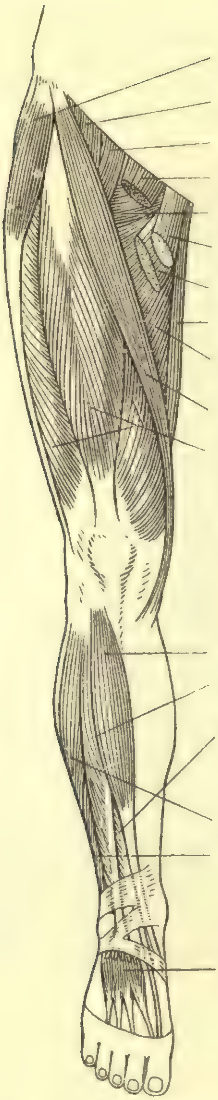


FIG. 67.—Innervation of the muscles of the lower limb. Front of the limb.

THE LOWER EXTREMITY

LESIONS OF THE CAUDA EQUINA

Anatomy. The spinal cord ends at the level of the first lumbar vertebra, and below this level the lumbar, sacral, and coccygeal roots

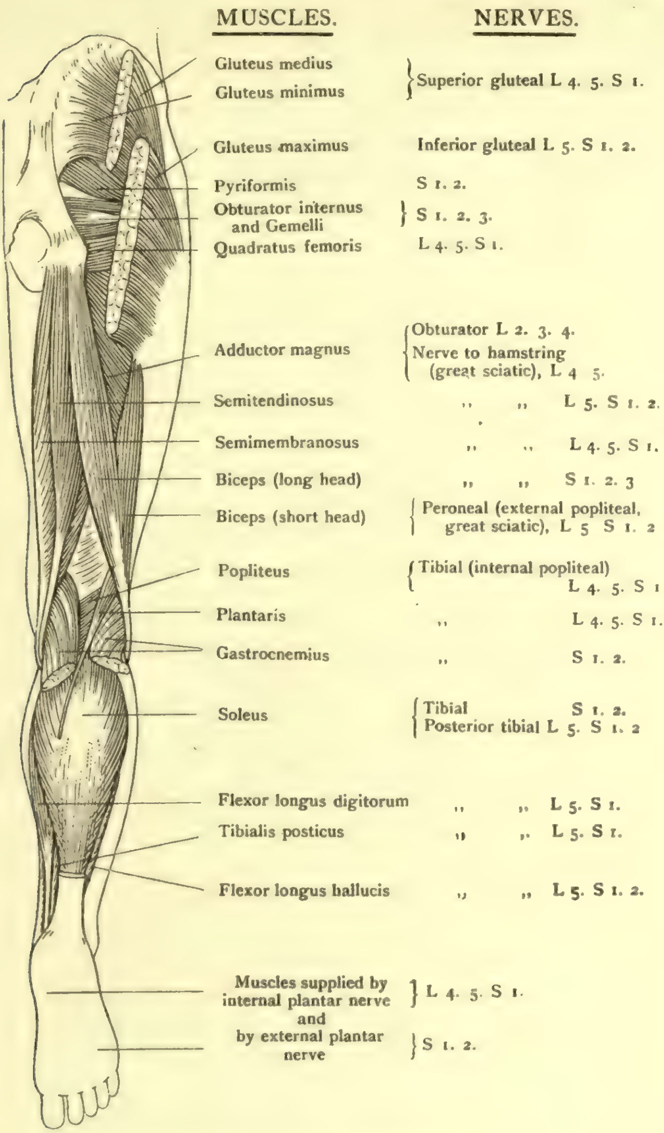


FIG. 68.—Innervation of the muscles of the lower limb.
Back of the limb.

are collected together to form the cauda equina. The nerve roots pass downwards within the dura and each pair of lumbar and sacral roots separates from the equina to pass outwards through their corresponding intervertebral foramina. It is obvious, therefore, that the lower the nerve root, the longer is its course within the vertebral canal.

The coccygeal roots are placed most centrally and from below upwards are added the fifth, fourth, third, second, and first sacral and the fifth, fourth, third, second, and first lumbar roots.

Etiology. The symptoms resulting from a lesion of the cauda equina will be determined by (1) the level of the lesion and (2) the position of the lesion as regards the arrangement of the nerve roots in the cauda equina.

Injury to the cauda equina in the mesial plane will involve the coccygeal and sacral roots, as they are placed most centrally; on the other hand, injury to one side of the mesial plane will only affect the roots passing downwards on that side below the level of the lesion.

The cauda equina is not firmly fixed in position and the nerve roots are fairly movable. Thus it is that even severe injuries to the lumbosacral spine may result in partial or total lesions of different roots in a very indiscriminate fashion.

Motor Distribution.—Most of the muscles of the lower limb derive their nerve supply from more than one root. This table is given merely as an aid to motor localization and does not imply that the various muscles mentioned are solely supplied from the root indicated.

TABLE SHOWING THE APPROXIMATE MOTOR DISTRIBUTION OF THE LUMBAR AND SACRAL ROOTS

Root.	*Chief Muscles Supplied.*
Lumbar 1 and 2 .	Psoas, iliacus, pectineus.
,, 3 . . .	Quadriceps, extensors and adductors of thigh.
,, 4 . . .	Tibialis anticus, extensors of foot.
,, 5 . . .	Extensors of foot and toes, and peronei.
Sacral 1 . . .	Calf muscles, flexors of foot and toes, hamstrings.
,, 2 . . .	Hamstrings and glutei.
,, 3, 4, and 5 .	Levator ani and perineal muscles.

Sensory Distribution.—It will be noticed that the front of the thigh is supplied by the first, second, and third lumbar roots, the inner side of the leg by the fourth lumbar root, and the outer side of the leg and dorsum of the foot by the fifth lumbar root. The first sacral root supplies the upper surface of the terminal joints of the toes, a 'golosh' area surrounding the sole of the foot, the whole of the under surface of the toes and sole of the foot and the posterior aspect of the heel and tendo Achillis, extending up in the centre of the leg to about the middle of the calf. This strip is bounded on its outer side by the fifth lumbar area and on its inner by the fourth lumbar area. The second sacral extends upwards on the posterior aspect of the leg to below the buttocks and is bounded in the thigh by the third lumbar area. The third sacral area expands over the buttocks to enclose the fourth and fifth sacral areas which supply the genitalia and surrounding area.

Symptoms and Signs of Lesion of the Cauda equina.

A. *Total Lesion of the Cauda Equina at the Level of the First Lumbar Vertebra.*

Motor.—There is complete flaccid atrophic paralysis of the muscles of the lower extremity with corresponding changes in the electrical reactions. There is loss of all movement from the hip downwards.

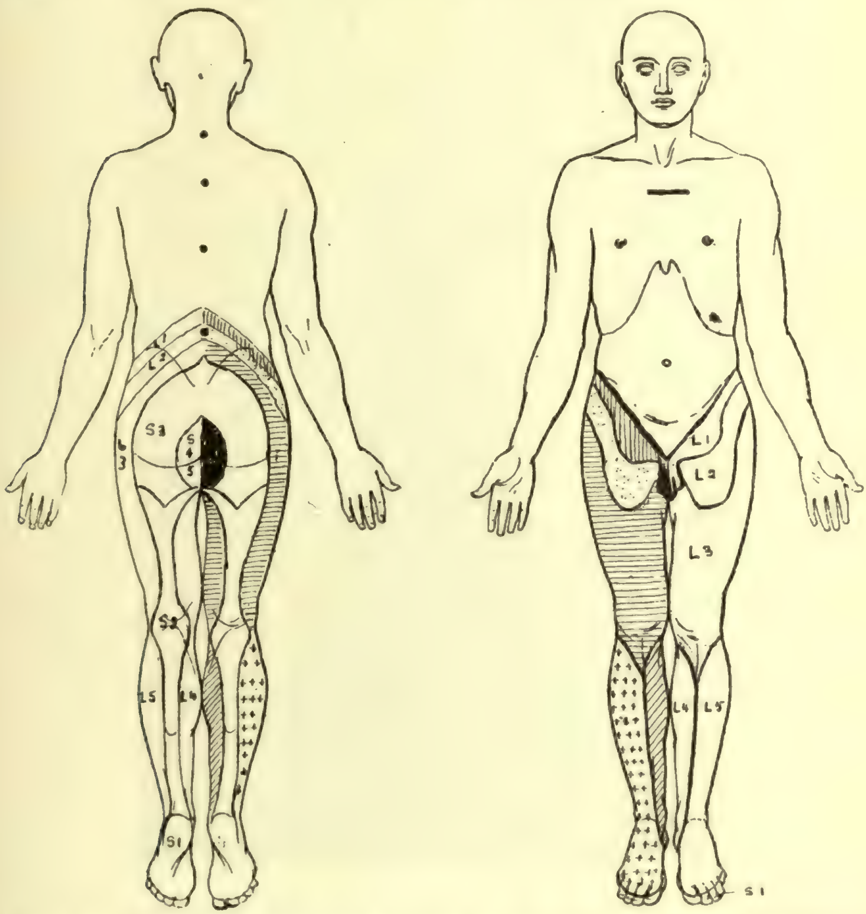


FIG. 69.—Diagram showing areas supplied by the lumbar and sacral posterior roots.

Sensory.—There is complete loss of sensation over the lower extremities up to the level of the groins in front, and over the genitals, buttocks, and sacral region, also in the bladder and rectum, and the patient has no sensation of the passage of urine and fæces. All sensation from the genitalia is abolished and no sexual actions can be performed.

Reflexes.—The knee and ankle jerks are absent; the cremasteric and plantar reflexes are abolished.

Sphincters.—There is complete loss of control over the urine and fæces,

Fig. 70.—Photograph showing the area of sensory loss resulting from a lesion of the cauda equina involving all the sacral roots. Compare diagram 69.

In this case there was weakness and wasting of the calf muscles. The ankle jerks and the plantar reflexes were absent and there was loss of control over the bladder and rectum.

with paralysis of the sphincter ani muscle. The urine dribbles away and motions pass without the patient's knowledge.

Trophic.—The trophic changes are severe, and it is practically impos-

sible to prevent the occurrence of bedsores, more especially over the sacrum and heels.

B. *Unilateral Lesion of the Cauda Equina at the Level of the First Lumbar Vertebra.*

In this case the motor and sensory symptoms will be limited to the side of the lesion with absence of the knee and ankle jerks and of the cremasteric and plantar reflexes.

The sphincters are not completely paralysed, and control, which is at first lost, is gradually restored.

Sexual sensation is diminished and sexual power is as a rule lost.

C. *Lesion of the Cauda Equina below the Separation of the Third Lumbar Roots.*

There is no paralysis of flexion of the hip and extension of the knee. All foot movements and flexion of the knee and extension of the thigh are lost.

There is loss of sensation below the knee and up the centre of the posterior aspect of the thigh and round the buttocks and genitalia.

The knee jerks and cremasteric reflexes are retained, but the ankle jerks and the plantar reflexes are abolished.

There is complete loss of sphincter control.

D. *Lesion of the Cauda Equina below the Separation of the Third Sacral Roots.*

There is no motor paralysis except of the sphincter muscles. The area of sensory loss is confined to the buttock region and a strip down the back of the thighs.

There is complete loss of control over the sphincters and loss of sexual power and sensation.

The knee and ankle jerks and the plantar reflexes are normal.

E. *Lesion of the Cauda Equina below the Level of the Separation of the Third Sacral Roots.*

The anal sphincter may escape, but there is loss of control over the bladder and rectum, and loss of sensation over the buttocks and genitalia.

Diagnosis. A study of the tables and diagrams given above will be of service in locating the position of a lesion of the cauda equina. In all cases of lesion of the cauda equina, the motor paralysis is of the lower motor neurone type. The sensory loss differs in character from that found in lesions of the central nervous system, and in distribution, from that of the peripheral nerves, and as a rule the area of loss to pinprick is greater than the area of loss to cotton-wool.

In partial lesions certain roots may escape and others be involved, so that the clinical picture presented may vary widely, but in all cases

the loss, whether motor or sensory, will be of the root type. The motor paralysis is rarely complete unless two or three adjacent roots are paralysed. The degree of interference with sphincter control and sexual power may vary, and in many cases recovery of these functions has taken place many months after the date of injury.

THE LUMBO-SACRAL PLEXUS

The plexus is formed by the anterior primary divisions of all the lumbar nerves and of the first three sacral nerves. It is separated by the sacro-iliac articulation into two parts, lumbar and sacral. The nerve of junction, entering into the formation of both portions, is the fourth lumbar nerve.

Lumbar Portion. The lumbar part of the plexus is formed in the substance of the psoas muscle, whence its nerves of distribution emerge on the posterior abdominal wall.

It is formed from the anterior primary division of the first three lumbar nerves and part of the fourth, with sometimes a communication from the twelfth thoracic nerve.

The nerves of the plexus are collateral and terminal.

Collateral.—The collateral branches are given off from the separate spinal nerves to the following muscles :

Quadratus lumborum . . .	L 1, 2, 3, (4)
Psoas magnus	L (1), 2, 3, (4)
Psoas parvus	L 1 or 2

Terminal.—The terminal branches of distribution are the following :

Ilio-hypogastric	L 1
Ilio-inguinal	L 1
Genito-crural	L 1, 2
External cutaneous	L 2, 3
Obturator	L 2, 3, 4
Anterior crural	L 2, 3, 4

The ilio-hypogastric and ilio-inguinal nerves are derived from the first lumbar nerve with an occasional contribution from the twelfth thoracic.

Ilio-hypogastric. The ilio-hypogastric nerve emerges from the outer border of the psoas magnus muscle, and traverses the posterior abdominal wall, lying on the quadratus lumborum muscle. It pierces the transversalis abdominis muscle, passing downwards and forwards between it and the obliquus internus to a point in front of the anterior superior spine. Here it pierces the obliquus internus muscle and emerges from the aponeurosis of the obliquus externus about one and a half inches from the crest of the pubis. It supplies the skin of the lower part of the

abdominal wall and muscular branches to the muscles between which it lies, and gives off a lateral branch which passes over the iliac crest supplying a small area of the skin of the buttock.

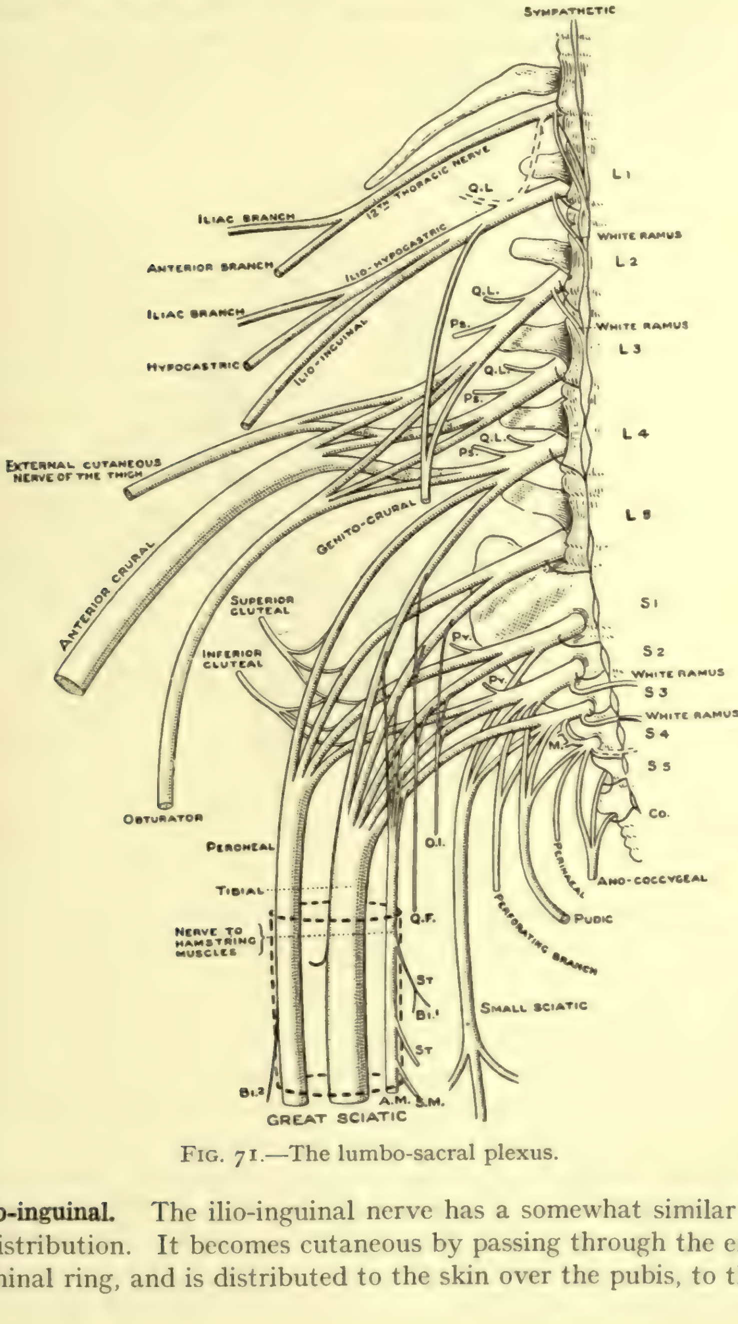


FIG. 71.—The lumbo-sacral plexus.

Ilio-inguinal. The ilio-inguinal nerve has a somewhat similar course and distribution. It becomes cutaneous by passing through the external abdominal ring, and is distributed to the skin over the pubis, to the root

of the penis, the base of the scrotum and the inner part of Scarpa's triangle.

Genito-crural Nerve. The genito-crural nerve is formed in the substance of the psoas muscle by branches from the first and second lumbar nerves. It divides in the groin into crural and genital branches. The crural supplies the skin over the outer part of Scarpa's triangle. The genital supplies the cremaster muscle.

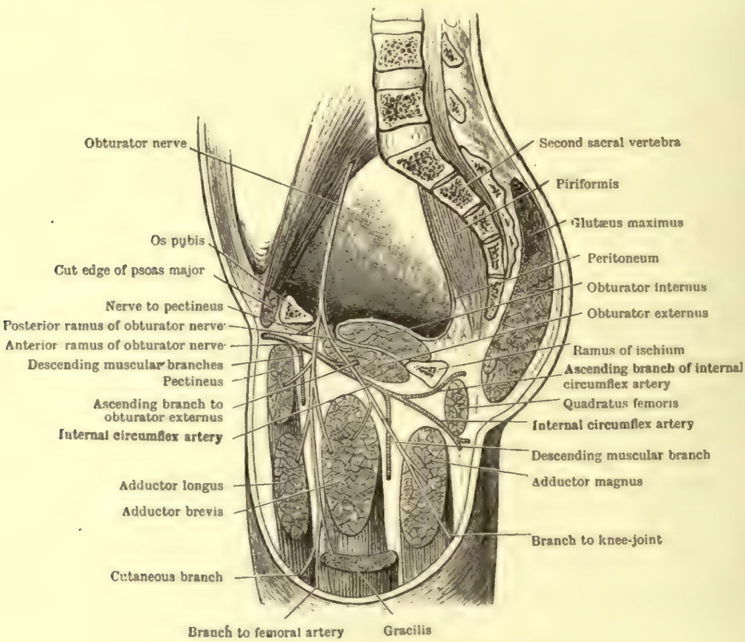


FIG. 72.—Scheme of the distribution of the obturator nerve.

The External Cutaneous Nerve. The external cutaneous nerve arises by two roots from the back of the trunks of the second and third lumbar nerves. It pierces the outer border of the psoas magnus muscle about its middle, passes across the iliacus muscle, beneath Poupart's ligament just below the anterior iliac spine, and makes its way over, under, or through the sartorius muscle, near its origin. It emerges three or four inches lower on the outer side of the thigh and then becomes cutaneous. It divides into anterior and posterior trunks for the supply of the skin on the front and outer side of the thigh in its whole extent.

The **Obturator** and **Anterior Crural** nerves arise from the anterior primary divisions of the second and third lumbar nerves, and part of the fourth. These subdivide in the substance of the psoas magnus into anterior or ventral and posterior or dorsal branches. The anterior com-

bine to form the obturator. The posterior to form the anterior crural nerve.

The Obturator Nerve. The obturator nerve passes vertically downwards in the substance of the psoas magnus, from the inner border of which it emerges at the pelvic brim. Passing external to the internal iliac vessels and the ureter, and lying in the extra-peritoneal tissue,

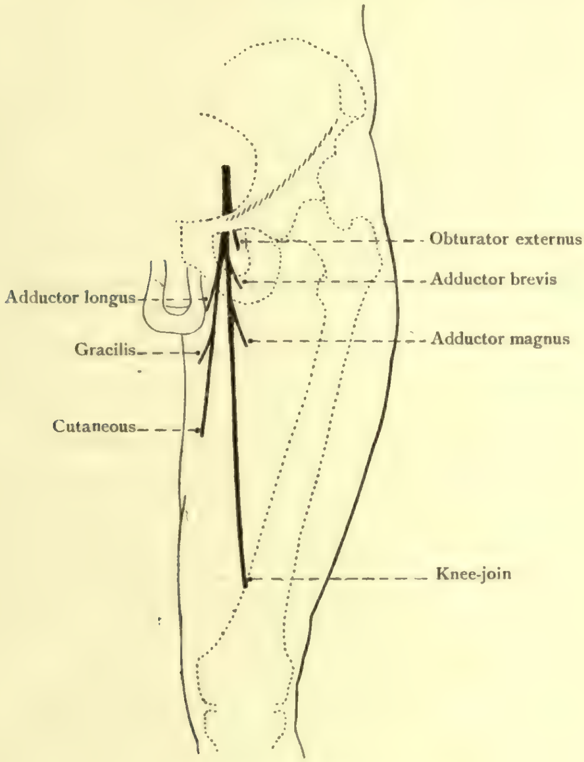


FIG. 73.—Obturator nerve.

accompanied by the obturator artery it enters the thigh through the obturator groove. In the groove it divides into two branches—superficial and deep. The superficial branch passes in front of the obturator externus and adductor brevis muscles, and behind the pectineus and adductor longus. It finally subdivides at the inner border of the adductor longus into its terminal branches, of which one supplies the femoral artery and the other, passing between the sartorius and gracilis, ends by supplying the skin of the inner side of the thigh in its middle third.

The collateral branches of the superficial part of the obturator nerve

supply the hip-joint, the adductor longus and gracilis, and sometimes the pectineus and the adductor brevis muscles.

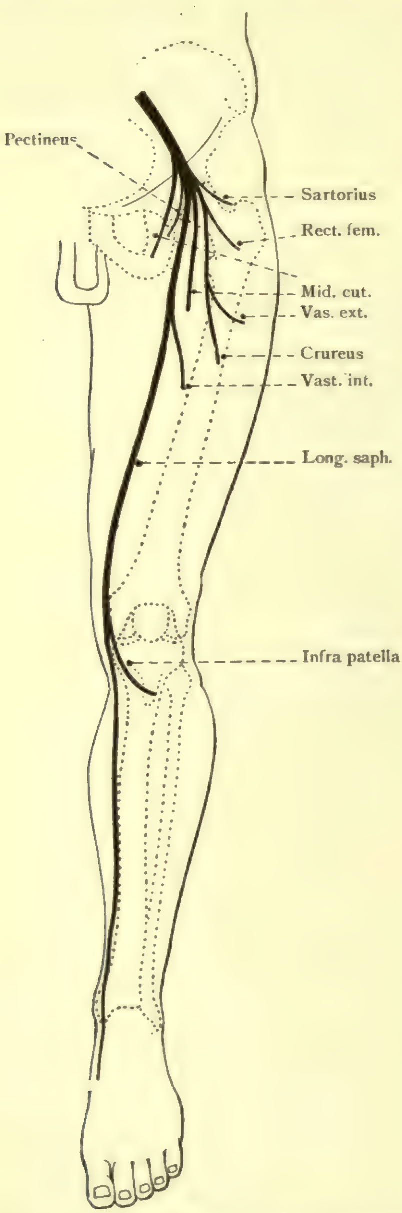


FIG. 74.—Distribution of anterior crural nerve.

The deep part of the obturator nerve enters the thigh after piercing the obturator externus muscle. It passes down the thigh between the adductor brevis and adductor magnus muscle, and after piercing the latter muscle it applies itself to the popliteal artery, and ends as an articular (geniculate) branch for the knee-joint.

Its collateral branches are the nerve to the obturator externus muscle, which arises before the nerve pierces the muscle and the muscular branches to the adductor magnus and adductor brevis. This muscle is sometimes innervated by the superficial part of the nerve.

Etiology. Owing to its short course, and its protected position, lesions of this nerve are rarely met with, more especially as injuries of such severity as to damage the nerve are likely to prove fatal owing to bleeding from the large vessels lying near it.

Diagnosis. *Motor.*—There is almost complete paralysis of adduction, but some movement may be present, owing to the fact that the adductor longus is partly supplied by the anterior crural nerve and the adductor magnus by a branch from the sciatic nerve. External rotation of the thigh, and flexion of the thigh on the pelvis, are also weakened. In short, the movements required to cross one leg over the other are interfered with.

Sensory.—There is a small area of sensory loss in the area of distribution of the nerve.

The Anterior Crural Nerve is the largest nerve of the lumbar plexus. It is formed in the substance of the psoas magnus by the union of the posterior trunks of the anterior primary divisions of the second, third, and fourth lumbar nerves, it extends obliquely downwards and outwards through the muscle to its outer border, from which it emerges in a groove between the psoas and iliacus muscles. Passing into the thigh beneath Poupart's ligament it divides in Scarpa's triangle into a sheaf of branches for the supply of the skin and muscles of the lower limb. In the thigh it lies external to the femoral vessels and outside the femoral sheath. The external circumflex artery passes outwards among the branches of the nerve near their origin.

Distribution. It supplies articular branches to the hip-joint and indirectly, by the nerve of the vastus internus muscle, to the knee-joint. It supplies muscular branches to the iliacus, sartorius, pectineus, and quadriceps extensor.

Sensory Distribution.—Its cutaneous branches are the two middle cutaneous nerves distributed over the skin over the front of the thigh as far as the knee ; and three internal cutaneous nerves—upper, middle, and lower—supplying the skin of the inner side of the thigh in its middle and lower thirds.

The terminal branch of the anterior crural nerve is the internal or long saphenous nerve. It passes down through Scarpa's triangle, lying external to the femoral vessels. It crosses the vessels in Hunter's canal and passes down between the sartorius and gracilis muscles, becoming cutaneous at the inner side of the knee. It passes down the inner side of the leg, over the internal malleolus, and terminates in the middle of the inner border of the sole of the foot.

It supplies the skin of the inner side of the leg in its whole extent, as well as the skin over the internal malleolus, and the inner side of the foot as far as the middle of the inner border.

It gives a patellar branch to the front of the knee.

Etiology. Cases of complete division of the nerve are not common in practice, for a wound above the point where the nerve begins to split up is likely to damage the femoral vessels with fatal results.

Diagnosis. Complete or partial lesions of the nerve to the quadriceps extensor and the internal saphenous nerve are fairly common.

Motor.—In these cases, extension of the leg at the knee is weakened Walking is possible, thanks to the tensor fasciæ femoris and the gracilis, which help to keep the leg stiff when the knee is extended, but progression is difficult, for if the leg becomes slightly flexed, the knee gives way at once, and the patient falls.

Sensory.—Sensation is affected over the front of the thigh, and inner side of the thigh, leg, and ankle.

Reflexes.—The knee jerk is absent or diminished.

Pain.—Pain in the distribution of the nerve may be severe at first, but as a rule it passes off in a few weeks.

FIG. 75.

FIG. 76.

Photographs showing area of sensory loss in a case of gun-shot injury which fractured the femur and injured the anterior crural nerve.

THE SACRAL PORTION

The sacral portion of the plexus for the lower limb is formed by part of the fourth lumbar nerve, the fifth lumbar, and the first two sacral, and usually a considerable portion of the third sacral nerve.

General Survey. The contributory part of the fourth lumbar nerve pierces the psoas magnus muscle on its inner side, and joins the anterior primary division of the fifth lumbar nerve to form the so-called lumbo-

sacral cord. This cord enters the pelvis in front of the lateral mass of the sacrum, and forms part of a broad band, the great sciatic nerve

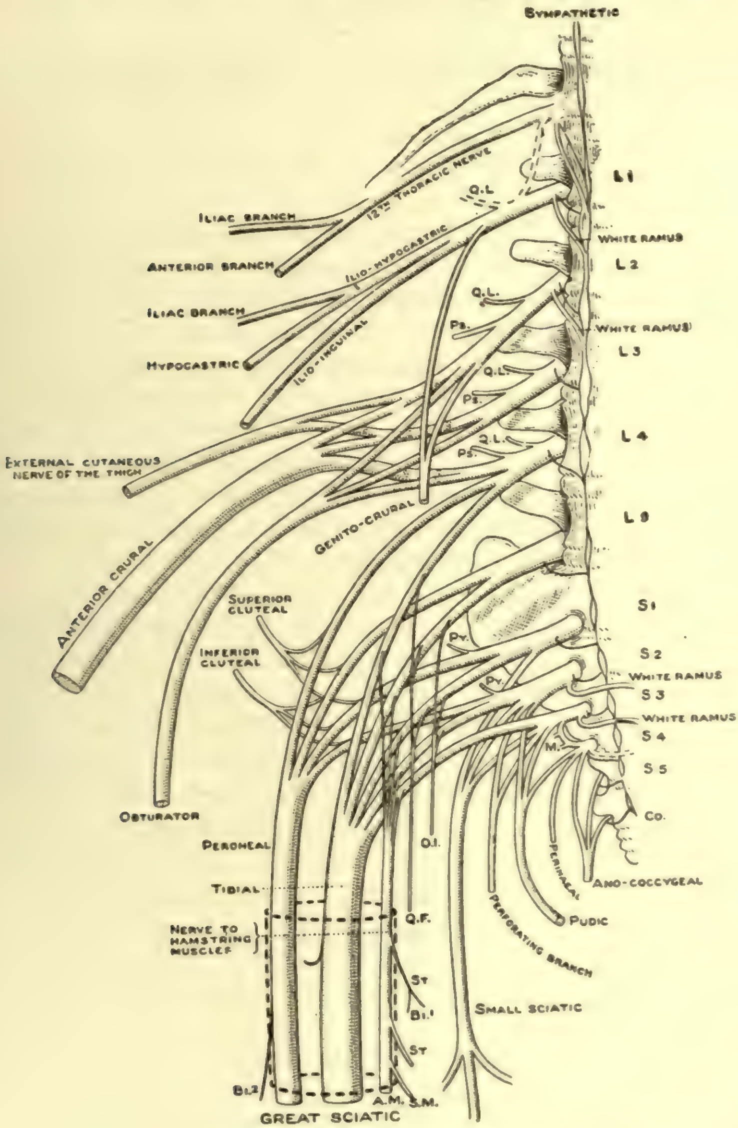


Fig. 77.—Lumbo-sacral plexus.

which is completed by the addition of the anterior primary divisions of the first two and a part of the sacral nerves.

The Great Sciatic Nerve enters the buttock, where it lies beneath the gluteus maximus, by passing through the great sciatic foramen

below the pyriformis muscle. Passing below the edge of the gluteus maximus midway between the great trochanter of the femur and the ischial tuberosity, it occupies the back of the thigh, covered by the hamstring muscles. It gives off from its inner side in one or two bundles the nerve to the hamstring muscles, and divides at a variable point into the external popliteal or peroneal and the internal popliteal or tibial nerves.

Not infrequently the peroneal and tibial nerves are separate from their origin.

Although the nerve to the hamstring muscles has a closer connexion than the peroneal with the tibial trunk, there is no doubt that these three nerves are separate and distinct in origin as in distribution.

The peroneal and tibial nerves separate from one another at a variable point. As already stated they may be separate from their origin, or the great sciatic nerve may divide at any point between the great sacro-sciatic foramen and the popliteal space. There is no interchange of fibres between the two nerves in any part of their course.

The Peroneal Nerve is formed by the union of the posterior or dorsal and anterior or ventral trunks which come from the fourth and fifth lumbar and the first two sacral nerves.

The Tibial Nerve is formed by the union of the anterior or ventral trunks of the anterior primary divisions of the fourth and fifth lumbar, and the first two sacral nerves, with the addition of a part of the third sacral nerve (n. bigeminus). As already mentioned, there may be no contribution from the third sacral nerve. These component trunks lie ventral to the trunks forming the peroneal nerve, and can be traced for a considerable distance in the great sciatic trunk before subdividing and reuniting to form the nerves of distribution associated with the tibial nerve.

The Nerve to the Hamstring Muscles, lastly, has similar individuality in regard to its origin. Emerging as one or two bundles of nerves from the inner border of the great sciatic (or tibial) nerve, it forms a distinct trunk on the inner side of the nerve in the buttock. Traced up to the anterior primary divisions, it is found to take origin from all the nerves concerned in forming the tibial trunk—by roots which lie on the ventral or anterior aspect of the tibial nerve. These trunks pass down and subdivide and reunite to form the nerves for the supply of the individual muscles.

Distribution of the Nerves of the Sacral Part of the Plexus.

Collateral Branches in the Buttock. There are two series of collateral branches arising in the buttock.

(*a*) *Three Posterior* (*Dorsal*) *Branches.*

(1) The nerves to the pyriformis are two small branches arising from the dorsal aspect of the first and second sacral nerves, which enter the muscle separately.

(2) The superior gluteal nerve arises from the back of the posterior trunks of the fourth and fifth lumbar and the first sacral nerve. It passes through the great sacro-sciatic foramen into the buttock, above the pyriformis muscle. It is placed deeply beneath the glutei—maximus and medius—and after supplying them it passes forwards to terminate in the tensor fasciæ femoris muscle.

(3) The inferior gluteal nerve arises from the back of the posterior trunks of the fifth lumbar and first two sacral nerves. Appearing in the buttock below the pyriformis muscle, it is distributed solely to the gluteus maximus muscle. It gives off in rare cases the nerve to the short head of the biceps muscle.

(*b*) *Two Anterior* (*Ventral*) *Branches.*

(1) The nerve to the obturator internus muscle arises from the front of the anterior trunks of the fifth lumbar and first two sacral nerves, or from the first three sacral nerves. Leaving the pelvis through the great sacro-sciatic foramen, it lies on the spine of the ischium in company with the internal pudic vessels and nerve, and passing through the small sacro-sciatic foramen it supplies the obturator internus muscle on its deep surface. It gives off the nerve to the superior gemellus muscle.

(2) The nerve to the quadratus femoris muscle arises from the front of the anterior trunks of the fourth and fifth lumbar and first sacral nerves. It passes through the buttock, concealed by the great sciatic nerve and by the obturator internus and gemelli muscles. It ends on the deep surface of the quadratus femoris, and supplies the nerve to the inferior gemellus.

The Distribution of the Great Sciatic Nerve.

In the thigh several branches are given off from the great sciatic nerve for the supply of the adductor muscles in the following order.

From the nerve to the hamstring muscles :

A branch to semitendinosus, which may arise as high as the lower border of the quadratus femoris.
To the long head of the biceps.
Adductor magnus.
Semimembranosus.

And a branch which arises from the peroneal bundle just down to supply the short head of the biceps.

The Great Sciatic Nerve.

Diagnosis. Results of complete division of the great sciatic nerve will depend upon the level of the lesion.

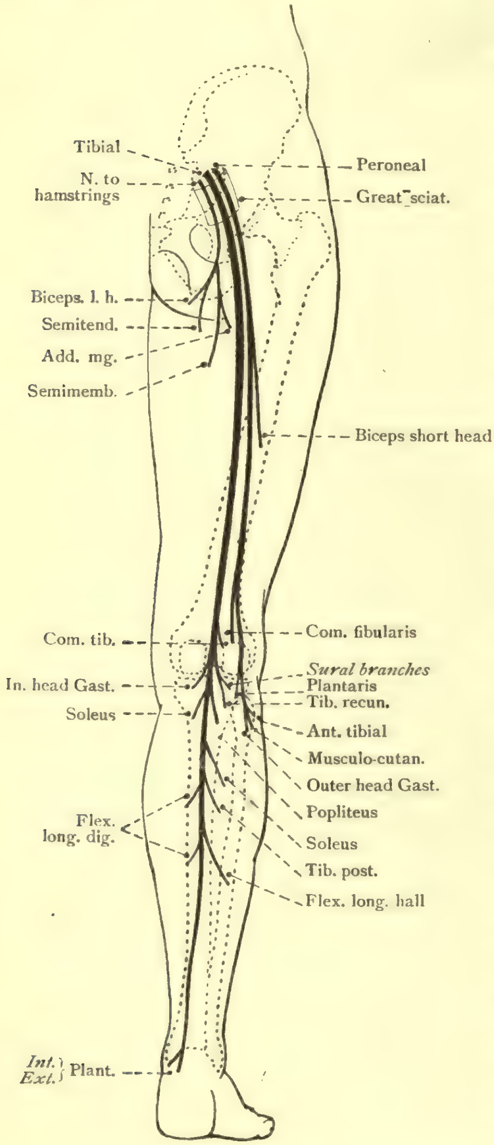


FIG. 78.—Distribution of great sciatic and tibial nerves.

Division High up in the Thigh.

Motor.—As a result of complete division of the sciatic nerve at this level there will be complete paralysis of all muscles below the knee and weakness of the muscles on the back of the thigh so that flexion of the knee may be impaired. The degree of weakness of the muscles of the back of the thigh depends on the level of the injury. The semi-tendinosus is most likely to escape as its nerve leaves the sciatic trunk in the buttock. The biceps is usually affected.

Owing to the paralysis of the leg and foot muscles there is foot and toe drop, and voluntary movements of the foot, ankle, and toes are impossible. The patient, however, is able to walk and his gait is peculiar; as a rule, the thigh is flexed and slightly abducted, his knee is raised unduly high in order that the dropped foot may swing clear of the ground. The foot flops on to the floor. The difficulty in walking is furthe increased by the fact that owing to the sensory loss the patient is unable either to feel his foot on the ground or to appreciate its position.

Wasting occurs in the back of the thigh and below the knee.

There is not much tendency for the development of contracture at the ankle, as both the flexor and extensor muscles are paralysed.

Sensory.—The area of sensory loss extends over the outer side of the leg, dorsum and outer side of the foot, sole of the foot, and over the heel and tendo Achillis. Sensibility is retained on the inner side of the leg, over the internal malleolus and over the middle third of the inner border of the foot extending to the inner side of the sole. The upper limit of the sensory loss varies considerably, but as a rule the loss to cotton-wool extends up in an arch to below the head of the fibula. The loss to pinprick rarely extends as high up. There is loss of sense of position in the toes and foot, and deep pressure is not appreciated when the foot is grasped between the thumb and finger, provided they are not placed upon the inner aspect of the foot. Vibrations are not felt when the tuning-fork is placed over the external malleolus.

In complete lesions trophic sores may result from injuries to the foot caused by pressure or ill-fitting boots. These sores are painless. In incomplete lesions, especially if the tibial portion of the nerve is involved, severe trophic disturbances may take place and fibrous ankylosis readily ensues. In these cases trophic sores are particularly apt to develop, and the occurrence of spontaneous pain at points in the sole of the foot is highly characteristic, resembling closely what is met with in cases of lesion of the median nerve in the arm.

Reflexes.—The knee jerk is retained, the ankle jerk and the plantar reflex are abolished.

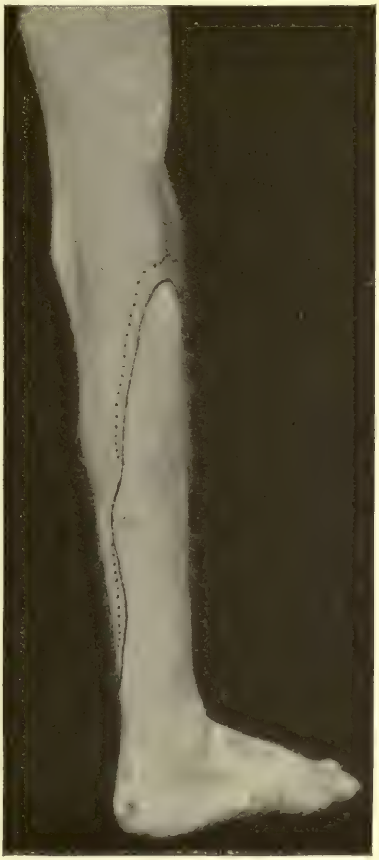


FIG. 79.—Photograph illustrating area of sensory loss in a high lesion of the sciatic nerve.

Terminal Branches of the Sciatic Nerve.

The Peroneal Nerve or External Popliteal Nerve.

As mentioned above a branch is given off in the thigh for the supply of the short head of the biceps, and with this may be associated a filament for the outer side of the knee-joint.

In the popliteal space the peroneal nerve follows the course of the

biceps tendon, and becomes superficial at the outer side of the space. It courses downwards and outwards, parallel to that tendon to a point just below the head of the fibula. It is placed immediately beneath the

FIG. 80.—Photograph showing case of paralysis of the sciatic nerve. Note the wasting and the area of sensory loss.

fascia lata, and there divides into its three terminal branches—anterior tibial recurrent, anterior tibial, and musculo-cutaneous.

During its passage through the popliteal space it gives off the following collateral branches :

Collateral Branches of the Peroneal or External Popliteal Nerve.

(1) Communicans fibularis, which passes down the back of the leg

under the deep fascia to unite with the corresponding branch (communicans tibialis) from the tibial nerve to form the short or external saphenous nerve.

FIG. 81.—Photograph showing case of paralysis of the sciatic nerve. Note the wasting and the area of sensory loss.

(2) Sural branches. Several branches arise from the peroneal nerve for the supply of the skin over the back and outer side of the calf of the leg.

Terminal Branches of the Peroneal or External Popliteal Nerve.

(1) *Anterior Tibial Recurrent* nerve, which is the highest of the three at their origin, and supplies the knee-joint and the upper fibres of the tibialis anticus.

(2) *The Anterior Tibial* nerve, which is intermediate in position at its origin. Clinging to the fibula, it passes downwards and forwards beneath the origins of the peroneus longus and extensor communis digitorum muscles.

On the front of the leg it is deeply placed, lying on the interosseus membrane, between the tibialis anticus and extensor proprius hallucis

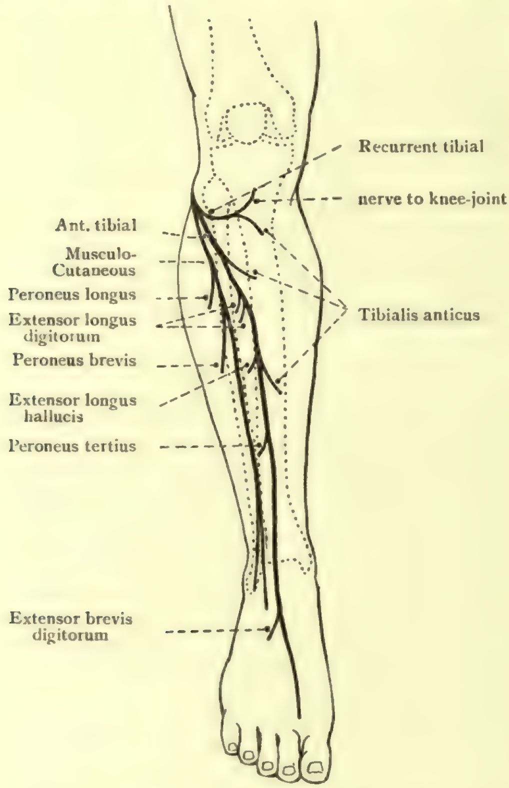


FIG. 82.—Peroneal nerve on the front of leg and dorsum of foot.

muscles. At the ankle it passes in front of the lower end of the tibia and is crossed by the tendon of the extensor longus hallucis.

On the dorsum of the foot it divides into its terminal branches, external and internal. In its course it is accompanied by the anterior tibial and dorsalis pedis arteries.

During its course down the leg it gives off branches to supply the extensor group of muscles on the front of the leg, in the following order :

Tibialis anticus.
Extensor longus hallucis.
Extensor longus digitorum.
Peroneus tertius.

The external branch ends in a distinct ganglionic enlargement, and supplies the extensor brevis digitorum muscle and the articulations of the tarsus.

The internal branch passes to the interval between the first and second toes, and supplies a small area of the skin of the dorsum of the foot and the adjacent sides of these toes.

(3) *The Musculo-cutaneous Nerve.*—The lowest in origin of the three branches is the musculo-cutaneous nerve. It passes obliquely downwards and forwards, lying at first between the origin of the peroneus longus and the fibula. It then passes down in the septum between the extensor and peronei muscles, and pierces the deep fascia below the middle of the leg. It divides into two terminal branches, internal and external, for the supply of the skin of the front of the leg and the dorsum of the foot and toes.

It gives off collateral branches during its passage down—

(1) To the peroneus longus muscle, whilst lying beneath that muscle. and

(2) A branch to the peroneus brevis muscle, given off in the upper third of the leg.

The terminal branches are cutaneous.

The internal branch supplies the skin of the front of the leg, the inner side of the foot, and the great toe ; and the skin between the second and third toes, and communicates with the internal saphenous nerve.

The external branch supplies the skin on the front of the leg and outer side of the dorsum of the foot ; and the skin between the third and fourth and fourth and fifth toes, and communicates on the outer side of the foot with the external saphenous nerve.

Lesions of the External Popliteal Nerve.

Motor.—In complete lesions of the external popliteal nerve there is wasting of the muscles lying on the anterior and outer surfaces of the leg, and the foot is dropped and inverted and the toes pointed ; the heel being drawn up by the action of the non-paralysed tendo Achillis. The patient is unable to dorsiflex his ankle or to evert it. Adduction of the foot can still be performed despite the paralysis of the tibialis anticus by means of the tibialis posticus muscle and extension of the distal phalanges of the toes can be carried out by the action of the interossei.

In old-standing cases the steppage gait may be more marked than in lesions of the whole sciatic nerve on account of the contraction of the flexor muscles and tendo Achillis.

Sensory.—The area of sensory loss will depend upon the level of the lesion. In high lesions it may extend almost to the knee. In other cases it is found only on the lower part of the outer surface of the leg and over

the dorsum of the foot on its upper and outer surfaces. It does not extend to the borders of the foot or over the terminal phalanges.

In lesions below the terminal division of the musculo-cutaneous nerve there may be little or no paralysis, and the sensory loss may be confined to the inner or outer portion of the dorsum of the foot.

FIG. 83.—Area of sensory loss in a case of lesion of the external popliteal nerve.

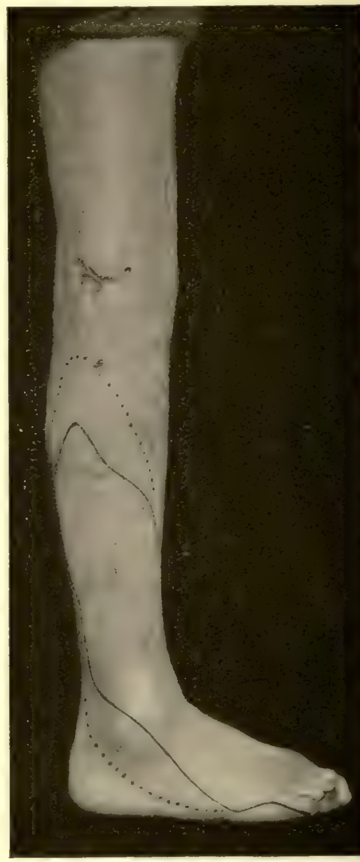


FIG. 84.—Area of sensory loss in a case of lesion of the external peroneal nerve.

In lesions below the head of the fibula, either the anterior tibial or musculo-cutaneous branch may escape.

Anterior Tibial. *Motor.*—If the anterior tibial branch is affected there will be paralysis of the tibialis anticus, extensor longus digitorum, extensor longus hallucis, peroneus tertius, and extensor brevis digitorum from above downwards with no paralysis of the peroneus longus or

brevis. There is paralysis of extension of the toes and dorsiflexion of the foot and elevation of the inner border of the foot is lost. If the injury occurs in the middle of the leg there may be only paralysis of the extensor longus hallucis.

Sensory.—There is little or no sensory loss. Partial anæsthesia over a small area extending over the first interosseus space and along the adjacent sides of the great and second toes is sometimes found.

Musculo-cutaneous Nerve.

When the musculo-cutaneous nerve is paralysed, if the patient dorsiflexes the foot, the unopposed tibialis anticus adducts it and rotates it inwards. In old-standing cases the patient may walk on the outer edge of the foot.

Motor.—There is paralysis of the peroneus longus and brevis, inability to abduct the foot or to raise its outer border.

Sensory.—There are sensory changes over the outer side of the dorsum of the foot and outer toes.

Reflexes.—The ankle jerk is preserved and the plantar reflex is flexor.

Injury to the lower third of the leg does not cause any motor paralysis, and the only sign of nerve involvement will be the disturbance of sensation.

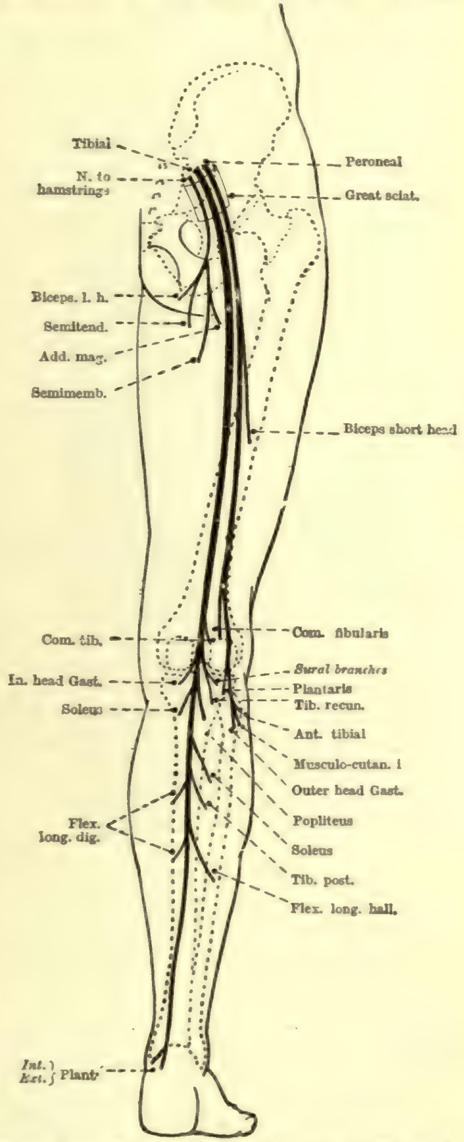


FIG. 85.—Distribution of great sciatic and tibial nerves.

The Tibial or Internal Popliteal Nerve.

The tibial or internal popliteal nerve corresponds to the median and ulnar nerves in the upper limb, and is a larger nerve than the peroneal. It extends down the back of the thigh, incorporated for a variable distance with the peroneal nerve in the great sciatic trunk, under cover of the hamstring muscles. It passes in

a vertical direction through the popliteal space, superficial to the vessels.

In the back of the leg the nerve, now known as the posterior tibial nerve, is placed deeply beneath the gastrocnemius, soleus plantaris and popliteus, and accompanies the posterior tibial vessels to the ankle. It lies on the inner side of the posterior tibial artery at its beginning, but is external to the artery at its termination.

Collateral Branches of the Tibial or Internal Popliteal Nerve.

In the thigh it gives off articular branches to the hip-joint and to the knee-joint.

In the popliteal space it gives off the communicans tibialis, which passes downwards between the heads of the gastrocnemius muscle. Piercing the deep fascia about the middle of the calf it unites with the communicans fibularis nerve to form the external or short saphenous nerve which supplies the skin over the lower third of the leg on the outer side and the outer side of the foot and little toe.

Muscular Branches.

The tibial nerve gives off branches in the popliteal space to the following muscles :

Gastrocnemius.
Plantaris.
Soleus.

During its passage down the leg, where it is known as the posterior tibial nerve, it gives off the following muscular branches to the

Soleus ;
Flexor longus hallucis ;
Tibialis posticus ;
Flexor longus digitorum.

Sensory.—The calcanean nerve is given off in the lower third of the leg and pierces the internal annular ligament close to the tuberosity of the os calcis. It supplies the skin of the heel and the back part of the sole of the foot.

Terminal Branches of the Post-tibial Nerve.

The post-tibial nerve terminates midway between the internal malleolus and the os calcis by dividing into its terminal branches—the internal and external plantar nerves, which correspond in general in their distribution in the sole of the foot to the median and ulnar nerves in the hand.

The *internal-plantar* nerve supplies the skin of the three and a half toes on the inner side of the foot and sends branches to the dorsum of the terminal phalanges of the corresponding toes. It supplies the following muscles :

Flexor brevis digitorum.
Adductor hallucis.
Flexor brevis hallucis.
First lumbrical muscle.

The *external-plantar* nerve (ulnar) crosses the sole of the foot obliquely between the first and second layer of muscles. It supplies the skin of the outer one and a half toes and the outer side of the foot and supplies the following muscles :

Abductor minimi digiti.
Flexor brevis minimi digiti.
All interossei.
2nd, 3rd, and 4th lumbricales.

Internal Popliteal Nerve.

Motor.—Complete division of this nerve causes paralysis of all the muscles on the back of the calf, and of all the muscles on the sole of the foot. Plantar flexion of the foot and flexion of the toes are impossible, and the foot cannot be adducted without being drawn upwards by the tibialis anticus. In standing the arch of the foot is flattened, and in walking the patient does not rise on his toes. Standing on tiptoe is impossible.

FIG. 86.

Photograph showing muscular wasting and area of sensory loss in a case of paralysis of the internal popliteal nerve.

Sensory.—Sensation is lost over the sole of the foot except along its inner border ; also on the under surface of the toes, along the outer border of the foot, and upper aspect of the terminal phalanges of the toes, and over the back of the heel and tendo Achillis.

Partial lesions of this nerve are characterized by the frequent occurrence of severe trophic and causalgic symptoms.

Reflexes.—The ankle jerk and plantar reflex are lost.

Posterior Tibial Nerve.

Motor.—This nerve is often injured by deep wounds of the calf. In these cases the nerves of the calf muscles escape injury, and if below the middle of the leg the paralysis may be confined to the sole of the foot.

The only appreciable motor defect is inability to abduct and adduct the toes through paralysis of the interossei. The foot, however, has

a characteristic appearance, it looks thin and bony, the sole is hollowed out, the ball of the foot is prominent, the phalanges are hyperextended at the proximal and flexed at the distal joints.

Sensory.—The area of sensory loss is confined to the sole of the foot.

Trophic sores and ulcers are not infrequent.

In irritative lesions the occurrence of severe pain may absolutely prevent the patient from using the foot.

FIG. 87.

FIG. 88.

Photographs showing muscular wasting and area of sensory loss in a case of paralysis of the internal popliteal nerve.

The Small Sciatic Nerve.

The small sciatic nerve derives its fibres from the 1st, 2nd, and 3rd sacral roots. It passes into the buttock below the pyriformis muscle in company with the inferior gluteal muscle and sciatic artery. Lying on the great sciatic nerve it proceeds to the lower border of the gluteus maximus, where it separates into its terminal branches. It is purely a cutaneous nerve, and supplies the skin over the lower part of the buttock and peroneal region.

Diagnosis. There is no motor paralysis, and the diagnosis will depend upon the discovery of sensory changes in the affected area.

PROGNOSIS IN PERIPHERAL NERVE INJURIES

BY

COLONEL E. FARQUHAR BUZZARD

PROGNOSIS IN PERIPHERAL NERVE INJURIES

General Considerations. The ability to give an accurate prognosis in cases of injury to peripheral nerves would be a great asset at the present time not only to the medical profession but to all officials who are concerned with pensions and pensioners. The problem, however, is beset with many difficulties which become more numerous in proportion to the variety of aspects from which it is studied.

If a nerve has been divided and skilfully sutured, if secondary complications in the form of contractures and arthritic adhesions have been avoided, and if post-operative treatment has been adequate in efficiency and duration, it is justifiable to expect some recovery in its motor and sensory functions. The expectation may be fulfilled and it may be possible to demonstrate the return of muscular contraction in response to voluntary and faradic stimuli and the recovery of sensibility in areas which had been insensitive. But the problem is not yet satisfactorily solved and cannot be until the restoration of function is reviewed in relation to the use to which the recovered limb is destined to be put.

For example, we may take the case of a violin player who has sustained a severe injury involving the ulnar or median nerves of his left arm and whose operation and treatment have, from a surgical point of view, been brilliantly successful after months or even a year or two of careful attention. Is the result a success if reviewed in the light of the patient's ability to return to the profession by means of which he used to earn his living? In all probability the answer must be in the negative. Much the same would apply to the case of a professional football player whose sciatic nerve had been divided and successfully treated. On the other hand, there are many instances of injuries to peripheral nerves in which the damage is due to compression, concussion, or contusion, and in which there has never been any anatomical division of fibres. In spite of complete loss of function for many days or weeks after the trauma the prognosis in these cases may be regarded as favourable and a complete return of functional activity probable.

Between these two extremes there are innumerable cases of partial injury in which the degree of restoration varies in relation to a number of factors such as (1) the severity of the injury, (2) the presence or absence of sepsis, (3) the presence or absence of complications, (4) the efficiency of treatment, and finally what may be termed the personal factor. The

last factor is one of great importance especially in the stage of re-education, some individuals responding readily and rapidly and others very slowly to this form of treatment.

Speaking generally, it may be said that injuries to nerves even when they involve complete division may under favourable circumstances be successfully treated in so far as a certain degree of usefulness is restored to a limb, but that if the parts involved are needed for highly specialized movements or for sustained effort they are almost certain to be found wanting.

This general consideration is of some importance and may affect the question of surgical intervention in particular instances. For example, a patient has sustained a severe injury to an external popliteal nerve, recovery has taken place to an extent which enables him to make all movements of his ankle with freedom when examined lying down. He complains that after walking more than a short distance his toes tend to drag and that he is obliged to wear some kind of support to enable him to get about his business. Would surgical intervention involving a resection of the damaged part of the nerve be justified ? Is it to be expected that the final result of such an operation after many months of treatment would enable the patient to dispense with artificial help ? The answer must be in the negative, judging from general experience and not from a few individual results of exceptional success attending such operations.

This is a question of prognosis which must be carefully considered when a secondary operation in cases of incomplete recovery is contemplated. Special consideration is needed when the nerve involved is important from a sensory point of view, for instance the median. In this case it would be unjustifiable to sacrifice good sensibility in the distribution of that nerve for any problematical improvement in its motor functions. A hand with imperfect sensibility in the thumb and first finger has lost nearly all its cunning, whereas many individuals can get along very well with a poor thenar eminence provided their delicacy of finger touch is retained.

As the expectation of recovery of function varies considerably in relation to individual peripheral nerves after primary or secondary suture has been performed, a brief consideration of each of the important ones is desirable.

Circumflex. Injuries to this nerve are rarely accessible to surgical intervention and are usually complicated by fractures of the head of the humerus or damage to the shoulder-joint. If no return of activity in the deltoid muscle appears during the treatment of the complications, the chances of securing a useful shoulder-joint are extremely poor and some plastic operation may be necessary in order to put the upper arm in its most serviceable position.

Musculo-spiral. This nerve gives the most favourable results of any after suture, and evidence of returning function is usually obtainable from four to eight months after the operation. The more proximal muscles are the earliest to recover. The extensors of the thumb are the most likely to fail, but this failure may be largely compensated for by a transplantation of the tendon of the flexor carpi radialis into the tendons of the extensor ossis metacarpi pollicis and the extensor brevis pollicis.

Musculo-cutaneous. This nerve also gives favourable results after suture in the majority of cases, although the biceps muscle may never attain its previous dimensions and power. If, however, the musculo-spiral nerve is intact any deficiency in the ability to flex the elbow is supplemented largely by the supinator longus and wrist extensors.

Median. When this nerve is sutured in the upper arm a good return of functional activity may be expected in the muscles supplied by it in the forearm. The median muscles of the thenar eminence may recover some degree of activity but rarely exhibit usefulness comparable with the normal. The most serious disability arises from the sensory loss in the first finger and especially in the skin over the terminal phalanx of the digit. Protopathic sensibility is often recovered, but epicritic sensibility may be delayed for years if it is ever properly restored. This constitutes a serious disablement for fine work with the fingers, especially when the right median nerve is involved in a right-handed person.

It may be pointed out here that the degree of disablement engendered by the loss of power in intrinsic hand muscles as the result of either median or ulnar nerve injuries varies enormously with the individual. We have seen instances of both types of cases in which handiness seemed little impaired and others in which the patients were seriously disabled. Much depends on the readiness to devote time and attention to re-educative training.

Ulnar. What has been said about the median applies to the ulnar, except that its terminal motor functions are more important and its sensory function less important than that of the former nerve. Hence less hesitation may be felt in sacrificing the sensibility of the inner side of the hand and the inner fingers provided an operation gives some hope of improving the action of the important interosseous muscles. Unfortunately these structures are difficult to resuscitate once they have fallen into disuse, especially if complications are present in the form of arthritic changes.

The prognosis in cases of severe injury to ulnar and median nerves in the same arm is very much worse than when the damage is confined to one nerve.

Obliteration or impairment of the main arterial supply to the hand must also be regarded in many instances as an unfavourable factor both in median and ulnar nerve lesions, especially the former.

Sciatic. Suture of the main trunk of the sciatic nerve in the thigh may lead to very satisfactory results as far as ordinary locomotion is concerned. On the other hand, the majority of cases are unable to dispense with some form of toe-lifting support if their occupations necessitate much walking. The muscles supplied by the internal popliteal division generally recover earlier and more completely than those supplied by the external popliteal division. A perfect result can only be claimed when the patient is able to run, jump, and clamber about ladders, scaffolding, &c.

Such a degree of functional restoration entails good sensibility in the sole of the foot, without which there is a considerable degree of disablement. For this reason the remarks made above in regard to secondary operations on the median nerve apply almost as forcibly to similar interference with the internal popliteal and posterior tibial nerves, preservation of sensibility in the sole of the foot being a prominent consideration.

Anterior crural. The writer has seen but few cases of injury to this nerve and those within his experience have been incomplete. Recovery has been the rule, although the ultimate result has not been up to the normal standard in regard to the power attained by the quadriceps muscle.

Brachial plexus. The prognosis in the case of injuries to the brachial plexus must necessarily vary in proportion to the severity of the damage inflicted, but, speaking generally, these cases show remarkable powers of recovery and it is wise to give them a much longer period of probation before performing an exploratory operation than in the case of the peripheral nerves. Some good results have been seen after suture of individual trunks, particularly of the 5th and 6th cervical. When a brachial plexus lesion is complicated by severe injury to the sub-clavian artery the prognosis must be regarded as less favourable.

The Evidence of Returning Function in Relation to Prognosis. It may be stated generally as an axiom that prognosis is favourable so long as signs of returning function are progressive, but a word of warning is needed in respect to one or two signs which are often regarded as distinct evidence of retained conductivity in a nerve which has been damaged. Tinel's sign affords evidence that there are fibres retaining their function passing through the site of injury, but unless it shows signs of progression and is followed by other symptoms of conductivity it must not be relied upon as a contra-indication to surgical intervention.

The presence of a faradic response in certain muscles which have lost their response to volitional stimuli is sometimes a trap for the unwary. The writer has seen a number of instances in which muscles have retained a good response to the faradic current for weeks and even months after injury to the nerve which supplies them, and which, on a subsequent exploration, has revealed a complete anatomical division. It appears

that in certain individuals some muscles even when degenerated respond to currents of much shorter length than usual, and thus give rise to hopes of regeneration which are not justified. The tibialis anticus muscle is particularly liable to display this anomalous reaction in the lower limb and the flexor carpi ulnaris in the upper.

A favourable prognosis, therefore, based upon the presence of a faradic response must be looked upon with some suspicion unless it is soon followed by other, more convincing, evidence of restored function.

Prognosis in Relation to Time of Operation. It has generally been supposed that the shorter the interval between the division and suture of nerves the better the result. This generalization is not supported by our experience of war wounds, and we are not in a position to say that there is a limit to the interval between injury and operation beyond which the prognosis is seriously prejudiced. We have seen as good and as rapid recoveries resulting from suture of the sciatic nerve two years after its division as those which follow the same operation performed within a few weeks or months of the date of injury.

No doubt the care with which the limb has been treated during the interval may be a factor of some importance, but from the surgical point of view it is never too late to mend.

OPERATIVE TREATMENT OF WAR INJURIES
OF THE
PERIPHERAL SPINAL NERVES

BY

Sir HAROLD J. STILES, K.B.E.

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GENERAL CONSIDERATIONS

As the operative treatment of peripheral nerve injuries frequently entails extensive, and sometimes difficult dissections, it is essential that the operator should possess a thorough practical knowledge of dissecting-room anatomy. If he has not already acquired this knowledge, he should either take a short course in the dissecting-room, or be content to serve a preliminary apprenticeship as assistant to a surgeon who is constantly operating on these cases.

In abdominal operations, one assistant is generally sufficient, but in operations on the nerves of the extremities, three are generally required, namely, one to steady the limb, a second to swab the wound and secure the vessels, and a third to take charge of the retractors.

As the dissection may be a long one, the operator should sit rather than stand, and should have the limb supported at a convenient height.

It is not advisable to apply a tourniquet to the limb, as much time has to be spent in securing the bleeding points after its removal, and the tendency to subsequent oozing into the tissues is greater than when no tourniquet is used ; moreover, the vessels often serve as a guide to the nerve and its branches. During the operation the wound should not be bathed with normal saline ; the best lotion is the patient's own blood.

The knife should have the keenest possible edge, which should be bulged into a slight belly a little behind the point, and the handle should be sufficiently heavy to give the instrument the proper balance.

The dissecting forceps should have toothed extremities to enable the nerve to be picked up by gripping the sheath only, and the spring of the forceps should not be too strong, otherwise the muscles of the operator's thumb will soon become tired.

In using the knife, clean, rapid, and decisive cutting should be done with the belly of the knife rather than scratchy work with the point. Accurate suturing of the wound is greatly facilitated by scratching the skin at right angles to the direction of the incision ; this is specially important, as the joint in the neighbourhood of the wound frequently requires to be flexed to prevent tension on the sutured nerve. While making the incision, it is an advantage to stretch the skin transversely between the forefinger and thumb of the left hand.

In making the skin incisions, it is hardly necessary to point out the importance of an accurate knowledge of the surface guides to the nerves. Should the original scar happen to be in the neighbourhood of the normal skin incision for exposure of the nerve, the skin incision should be modified so as to enable it to be excised. In this connexion, it may in certain cases be advisable to excise the scar at a preliminary operation, this procedure

at the same time being a useful indication as to the presence or absence of latent sepsis.

The dissection to expose the injured nerve should err on the side of being too extensive rather than too limited, and the importance of exposing the nerve above and below the lesions in the first instance cannot be too strongly insisted upon. This is especially important when the nerve is embedded in or displaced by scar tissue or callus.

While the writer is careful to use gloves in all septic cases, he considers it a distinct asset to be able to dispense with them where rapid and delicate dissecting work is required; but the omission of gloves must not be attempted unless the surgeon has learned how to disinfect his skin and at the same time maintain its smoothness. Nor is it necessary in performing nerve dissections to protect the wound from the adjacent skin by clamping gauze to its cut edges. By so doing, one only encumbers the field of operation unnecessarily, and by covering the surface-landmarks the difficulties of the dissection are greatly increased.

In freeing the nerve, the operator should conserve the branches as far as possible; the best way to avoid them is to know exactly where to expect them.

During the dissection it is often a help to flex the limb a little so as to take the tension off the nerve and allow also of the retraction of the adjacent structures. The nerve should, of course, be handled with the greatest possible gentleness. The advantage of toothed dissecting forceps has already been referred to.

As already stated, the nerve is often adherent to or surrounded by, and sometimes considerably displaced by, an abundance of cicatricial tissue which binds it down to the adjacent muscles, which have themselves been more or less extensively injured. The dissection, therefore, must frequently be carried wide of the injured nerve in every direction, and it is most important that the muscles and tendons, as well as the nerve, should be freed from all cicatricial tissue. When the injury involves one of the nerves of the forearm, it may be necessary to combine the suturing of the nerve with a repair or transplantation of one or more of the adjacent tendons.

The nerve lesion itself must now be dealt with, but, before this is done, all the vessels should be tied so as to get rid of the forceps. Next, the degree of excitability of the nerve to the faradic current should be ascertained, and, while this is being done, the limb should be carefully exposed distal to the lesion; hence the disinfection of the skin should be continued to its extremity. Attention is called to the possibility, from spread of the current, of mistaking contraction of opposing muscles for movements of the muscles that are being watched. Again, although stiffness of the fingers should, as far as possible, be dealt with before

operating, this factor may introduce a difficulty in eliciting or translating the electrical findings.

If the lesion be a complete one, the bulbous or cicatricial extremities should be amputated with a very keen-edged knife, the nerve being meanwhile supported; and enough of the stump should be removed to expose apparently normal nerve bundles throughout the entire face of both stumps. If the nerve has not been completely divided, all cicatricial tissue should be removed from its sheath, after which the nerve should be carefully palpated to ascertain its degree of induration, and whether or not there are any localized cicatricial or gliomatous nodules in its substance.

If the nerve has been completely divided, the cicatricial, or neuromatous, stumps should not be amputated until all is ready for suturing. In amputating the ends, the nerve should be carefully supported so that a clean cut may be made, and for this purpose a very keen-edged knife should be used.

If, on stimulating the nerve above the thickened or bulbous portion, it is found that the muscular response is fairly good, it is often advisable to incise the involved portion longitudinally in one or two places; if, on the other hand, the faradic response is feeble, an exsection should be done and enough removed to expose nerve fibres free from all scar or neuromatous tissue. In dealing, however, with partial lesions of nerves, no hard and fast rules can be laid down; each case must be judged on its own merits. Personally, if in doubt, the writer is inclined to favour exsection, provided always he is satisfied that the two stumps can be brought into apposition without tension after the whole of the damaged segment has been removed.

With regard to closure of the wound, subcutaneous sutures are unnecessary, and their introduction only serves to prolong the operation. It must be remembered, however, that wounds in the long axis of the limb may give rise to a little tension, so that the sutures should be left in for ten days or so. Silkworm gut is the best material to use.

With regard to drainage, it is seldom necessary to introduce a tube, especially if interrupted sutures are employed, when all that is needed is to leave an interval between one or two of the stitches sufficient to admit of the escape of the blood-stained serum.

When flexion of the adjacent joint is necessary to take the tension off the nerve, the limb should be carefully splinted, and the first dressings should not be left entirely to the nurses. It is hardly necessary to point out that those in charge of the after-treatment should not be in too great a hurry to straighten the limb.

Where joints have to be flexed to allow of approximation of the segments in cases of suture, the question of how soon after operation

extension should be started and completed is important. The exact time after operation at which firm union occurs at the suture-line is not definitely known, and, therefore, in this connexion, it is better to err on the side of safety. The pain experienced by the patient when tension is put on the nerve is a useful indication as to the rate at which the extension of the flexed joint should be proceeded with. It should be pointed out, however, that if extension of the joint is begun before the new axones have grown into the distal segment, rupture of the suture is possible without pain. For example, the usual practice at the Edinburgh War Hospital in the case of a sciatic nerve suture requiring knee flexion to an angle of 90° for relaxation purposes is to wait for a period of four to six weeks from the date of operation before commencing to extend the knee ; gradual extension, a few degrees every week, is then proceeded with, employing two months more before obtaining complete extension. In no case has limitation in extensibility occurred as a result of flexing joints for such periods. A retaining splint is advisable in these cases, as extension of the joint may otherwise inadvertently take place.

Increased experience has convinced the writer that the tendency has been to delay operation too long. We are justified in delaying if there is definite evidence that improvement is taking place, and this is more likely to happen if the nerve has been contused as a result of a fracture, or if the symptoms are due to the pressure of callus. In such cases the improvement is progressive, and often ends in complete recovery. In cases, however, where the nerve has been directly injured by a bullet or piece of shrapnel, it is a mistake to wait, although the lesion may be only partial. Many of these partial lesions are attended with severe pain, with aggravated trophic disturbances and with cicatricial or reflex contractures. In such cases valuable time is wasted in waiting for a recovery, which in the end is only very partial. The operation can do no harm, the wound is healed in a fortnight, and the exploration enables us to ascertain the exact nature of the lesion. The pain, the trophic changes, the reflex spasm, and the contractures often rapidly disappear. In short, the operation will not only expedite the recovery, but will at the same time render it more nearly complete. The majority of authors recommend a delay of from three to six months to avoid the risk of lighting up latent sepsis. Unfortunately, even a delay of six months is no guarantee against this danger. For some time past our practice has been to apply firm, and then heavy, massage to the wound as soon as it has completely healed. If this causes no inflammatory reaction, operation may be undertaken within two or three weeks from the date of healing.

While in some cases the freeing of the nerve is a very simple matter, in others it may be difficult on account of adhesions to vessels or from the fact that the nerve is embedded in dense scar tissue or bone callus.

It occasionally happens, too, that the nerve has become considerably displaced from its normal course, and when this is the case, the operator may divide it accidentally, *unless he is careful to expose it on the proximal and distal side of the lesion before dealing with the lesion itself.*

In cases in which there is no response to the faradic current clinically, the nerve may sometimes be traced intact through a long stretch of dense scar tissue or along a deep groove in callus. After the nerve has been completely freed, it is carefully examined by inspection, by palpation, and by the faradic current (see p. 149).

Inspection may reveal the nerve to have an almost normal appearance, and yet the faradic response may be very feeble or even entirely absent. In such cases the nerve is generally somewhat atrophied-looking, and on palpation the impression gained is that the sheath is imperfectly filled, giving the nerve a ribbon-like, rather than a cylindrical, feel; another important feature of these cases is that the condition above described may extend for several inches. The indications here are to be content with freeing the nerve rather than doing a resection, and especially is this the case when the dissection has revealed evidence that the nerve has been compressed. In these cases the extent of the lesion and its imperfect delimitation make the more radical operation of resection unsuitable, at any rate until neurolysis has been given a chance.

More frequently, the freed nerve will be found to be thickened, and more or less firm and indurated, and this may take place either in a uniform or nodular manner. Not unusually, two nodular thickenings are separated by a short interval in which the nerve is shrunk. This generally signifies that the nerve fibres have been severely contused or ruptured, while the sheath has remained intact. In other cases, the lesion is represented by an elongated or more or less fusiform thickening of the nerve, which is generally, though not invariably, of a firmer consistence than the normal nerve. From the operation point of view, it is important to remember that this thickening may be almost confined to the sheath, and when this is the case, the thickening is generally secondary to an extravasation of blood around the nerve or to the spread of suppuration along the perithecal cellular tissue. In one instance, there were three thickenings of the sheath of the sciatic, each corresponding to the position of a drainage tube. It is necessary to remove the thickened sheath with scissors curved on the flat before undertaking a more detailed investigation of the nerve. At this stage the question will often arise as to whether the operator is to be content with merely freeing the nerve, or whether he should proceed to do a resection followed by end-to-end suturing. This is often a very difficult question, especially when the faradic current elicits a fairly good response in some of the muscles supplied by the nerve below the lesion. Out of 500 nerve opera-

tions performed at the Edinburgh War Hospital, the nerve has been resected in practically 50 per cent. of the cases. In a few cases, patients whose nerves were merely freed have had to have the lesion resected at a subsequent operation on account of the insufficiency or absence of improvement. Looking back on these cases in the light of present experience, the writer is satisfied that he would now do a resection in several of the cases in which neurolysis was done, and in a few cases he would now do a neurolysis where formerly he had done a resection. Every case must be treated on its own merits. For further information the reader is referred to the chapter on the Pathology of Peripheral Nerve Lesions, as well as to that dealing with the electrical examination of the nerve. But, while it would be useless to attempt to lay down hard and fast rules which would apply to all cases, a few words may be said with regard to the more doubtful ones. If, after examination by inspection, palpation, and the faradic current, we are still in doubt, the next thing to do is to incise the injured area longitudinally. Should the cut surface reveal nothing but fibrous scar tissue, resection is indicated ; if, on the other hand, bundles of nerve fibres can be traced through the thickened segment or through the neuroma, it is not usually necessary to resect the nerve. In a case where certain fibres are destroyed, it is necessary to consider the relative value of the two sets, and if those destroyed are of vital importance, it may be wise to sacrifice the intact fibres as resection gives the only chance of adequate recovery. A good example of this is in a lesion of the median in the upper arm where the function of the index finger and thumb is lost, while that of the pronator teres, the flexor carpi radialis, and palmaris longus is present ; resection would be advisable in such a case. On the other hand, if the index finger and thumb were functioning and the pronator teres and flexors of wrist gone, a policy of conservatism would be best ; in the latter case the retention of sensibility in the median distribution would be a preponderating factor in favour of conservatism. Sometimes it is advisable to make a second longitudinal incision into the nerve ; by incising the sheath, tension is relieved and harmful pressure is gradually removed from the nerve fibres, and this procedure, along with the neurolysis, may be sufficient to initiate recovery of function. The most difficult cases are those in which the cut surfaces of the lesion present a firm, pinkish, homogeneous appearance without any macroscopic fibrillations. Although the microscope often reveals the presence of young axis cylinders in the neuroma, they have failed in many cases to enter the nerve on the distal side of the lesion. Such thickenings should, therefore, be resected, and especially is this the case when the stumps can be brought into apposition without having to divide important motor branches.

In partial lesions of the nerve, where only a portion of the circum-

ference has been injured, the question is less complicated, as the unilateral neuroma may often be excised without having to resect the whole thickness of the nerve. To prevent undue kinking in cases of partial resection and suture, it is often an advantage to split the nerve longitudinally before suturing, so that the uninjured portion runs a wavy course instead of being sharply angled. This is specially advantageous in dealing with unilateral injuries of the sciatic nerve. If considerably more than half the fibres have been divided, it is wiser to do a complete resection to enable the partially divided nerve to be accurately sutured.

When the nerve has been completely severed and the ends have become separated, or when a section of the nerve has been destroyed so that a wide gap intervenes between the stumps, the aim of the operation should be to effect an end-to-end suturing of the prepared stumps, successive slices being removed in a proximal and distal direction respectively until healthy, or at any rate almost healthy, nerve bundles are exposed. In slicing the nerve it is important that a sharp knife be used and the sheath of the nerve segments be held firmly and accurately by tooth forceps, to avoid making anything but a clean transverse section. In determining how much to resect, special attention should be paid to the condition of the fibres on the proximal side of the lesion; it is important when trimming the stumps to attack the proximal end first, because if a doubtful part has to be left in order that the ends may be approximated, it is better that it should be in the distal segment. Before slicing the bulbs, however, the operator, for the reason stated later, should satisfy himself that after having done so, the ends can still be approximated. Before suturing the prepared stumps, all scar tissue should be removed, muscles and tendons should be freed from adhesions, and, if necessary, sutured or otherwise repaired. Again, before suturing the stumps, all bleeding should be carefully arrested and hæmostatic forceps removed. In some cases it is advisable to sew up part of the skin incision before carrying out the suture of the nerve, e. g. in lesions in the axilla where adduction of the arm is necessary to obtain coaptation of the stumps.

Before, however, the nerve is sutured a stitch should be introduced into corresponding aspects of the proximal and distal portions of the sheath, an inch or two from the stumps; these are for the purpose of acting as temporary guides to prevent axial rotation of one stump upon the other while they are being sutured. In cases where there was physical continuity before resection, the guides should be inserted before the nerve is divided.

With regard to the suturing of the stumps themselves, either fine linen thread, fine silk, or thin catgut may be used. The writer prefers the No. 160 linen thread supplied by Messrs. Turnbull & Wilson, drapers, Edinburgh. An objection to chromic catgut is the irritation produced

by the chromic acid. The sutures should take up the sheath only, and for their introduction either a fine sewing needle or a fine curved needle may be used according to the option of the operator. The sutures need not be more numerous than is necessary to retain all the nerve bundles within the sheath, and the amount of tension of each suture only moderate; usually from four to six sutures are sufficient for a nerve the size of the median. Only enough of the sheath should be included in the suture to ensure an efficient grip being obtained ; if too much is included, inversion is very liable to occur. It is recommended that the first two sutures be introduced at opposite aspects of the circumference ; after tying them, they are left long so that they may be used to steady and rotate the nerve while the remaining sutures are being introduced.

Special ring forceps or a small size of Lane's fenestrated tissue forceps are convenient instruments for retracting or steadying the nerve. Fine toothed forceps are employed to take up the edges of the sheath while the sutures are being introduced.

Some operators favour the envelopment of the sutured stumps in a sheath of fat or fascia lata, others prefer to slide a portion of a vein over the suture line, while others again make use of Cargile's membrane. The idea is to prevent the nerve from becoming adherent to the adjacent tissues and to prevent also the ingrowth of fibrous tissue between the sutures. The writer is of opinion that *all such devices only serve to set up the very mischief they are intended to prevent.* The few cases he has operated on in which one or other of these methods has been employed at a former operation, have only served to confirm this opinion. All that is necessary is to see that the sutured nerve is not left in contact with scar tissue, bare bone, separated periosteum, or the deep surface of the skin opposite the suture line. Healthy muscle, fat, or loose cellular tissue form the best and most natural bed for a nerve.

We have now to deal with a case in which the injury to the nerve has been more extensive, and where there is considerable doubt as to whether a direct end-to-end suture can be effected. It is safe to state that those who have had a large experience in operating on war injuries of the peripheral nerves would now be able to obtain an end-to-end suture in cases in which, from insufficient experience, they were, in the early part of the war, unable to do so.

Let us take, by way of example, extensive destruction of the median nerve in the middle third of the upper arm. As this nerve gives off no branches until it reaches the elbow, it may straightway be freed from this level up to the pectoralis minor muscle. This having been done the next step is to see if the ends can be brought into contact after fully flexing the elbow, and at the same time bringing the arm to the side. Should this not suffice, the next thing to do is to stretch the two portions

of the nerve ; this is done by grasping the bulbous ends with artery forceps and making gradual traction first on the one stump and then on the other. It should be observed that it is of no use attempting to lengthen the nerve by traction unless it has been completely freed, and the greater the length to which it is freed, the more it can be lengthened. Observe, too, the importance of making the traction before the bulbs are removed. Should the ends still fail to meet, or rather should the bulbs still fail to overlap so that the stumps when freshened would not meet, a further gain can be got by mobilizing the pronator teres muscle, so that the branches which are given off by the median in the upper part of the forearm may be isolated and stretched along with the main trunk. The mobilizing of the pronator teres and the division of the tendinous arch of the flexor digitorum sublimis muscle also help to shorten the course of the nerve, because when the elbow is flexed the nerve instead of being tacked down comes forward like a bowstring.

If this fails, what next ? Fortunately we have still another procedure, and that a valuable one, which we can draw upon, and that is to suture the bulbous ends together, or as nearly together as they will come, using thread strong enough to stand the strain of the traction. While this is being done the limb must be held with the arm well adducted and the elbow fully flexed. A fortnight later the elbow is gradually extended so that from six to eight weeks after the operation full extension is reached. If still more traction is deemed advisable, the limb may be gradually abducted from the side by means of a splint provided with a lengthening screw. After the arm has reached the horizontal plane, or nearly so, the nerve is again cut down upon, when it will be found that it has become so stretched that with the arm again adducted and the elbow flexed, the bulbs can be removed and the freshened stumps approximated. This may with advantage be termed the Two-stage Slow-stretching operation. In the opinion of the writer this is a valuable procedure which should be resorted to in preference to such alternative operations as the nerve flap operation, nerve grafting, nerve anastomosis, bone shortening, or bridging with cat-gut, calves' arteries, &c. (Fig. 89.)

To illustrate another principle, we will suppose we are dealing with an extensive lesion of the median nerve in the middle of the forearm. The important point here is to dissect out and follow both proximally and distally all the motor branches which the median gives off at the bend of the elbow and upper part of the forearm. The details of the operation will be given later on (see p. 178). When this has been done, the trunk of the nerve is freed as far above the elbow as necessary. By applying traction to the upper bulb, it will be found that the extensively freed portion of the nerve proximal to the lesion can now be pulled well down into the forearm, because the dissected out branches of the median now

offer no hindrance. Their origins become approximated towards their points of entrance into the muscles; in other words, these branches become relaxed instead of stretched when the median is pulled downwards. This is all the more important as, owing to the fixation of the median at the wrist, very little can be gained by upward traction of the nerve distal to the lesion. We may therefore lay it down as a principle that, in attempting to obtain an end-to-end junction after an extensive nerve resection, full advantage should be taken of a long proximal dissection, and while the main trunk is being freed, any motor branch or branches which are encountered must be freed as far as possible in both

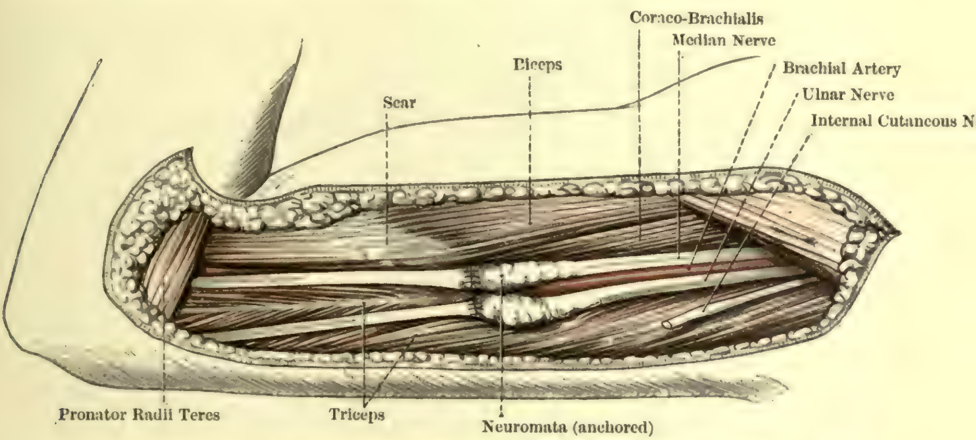


FIG. 89.—Operation for extensive lesions of the median and ulnar in the arm. The nerves felt hard for some distance above the neuromata, so that if all the unhealthy part had been resected, end-to-end suture would have been impossible Therefore the neuromata were anchored at the first operation with the joints flexed. After a course of gradual stretching of the joints (and indirectly of the nerves), a second exploration was made and, after resection of the unhealthy parts of the nerves, end-to-end suture carried out with the joints again flexed.

directions. In this connexion, attention should be drawn to the anatomical fact that the motor branches which are furnished to limb muscles which belong to the same group, almost invariably arise close together from the parent trunk; moreover, by dissecting upwards the individual branches along the trunk (by splitting its sheath), they are generally found to group themselves into a common bundle which can be dissected still farther upwards. These statements apply not only to the branches of the median in the upper part of the forearm, but also to the corresponding branches of the ulnar and still more so to the branches of the musculo-spiral to the triceps, and best of all perhaps, to the branches of the sciatic which go to supply the hamstring muscles, with the exception of the branch to the short head of the biceps, which is explained by the

fact that morphologically this muscle represents a displaced portion of the gluteus maximus muscle.

Limbs which have been flexed in order to allow of the approximation of the divided ends of the nerve must be carefully splinted. To enable the joints to be gradually extended, hinged or bendable splints are an advantage, and the splints should be retained until complete extension of the joint has been reached ; otherwise the stumps may be inadvertently torn apart at the suture line. The special splints used will be referred to when dealing with the individual nerves.

INJURIES TO THE NERVES OF THE UPPER EXTREMITY

BRACHIAL PLEXUS

Surgical Anatomy. It will conduce to a clearer understanding of the operative procedures called for in dealing with the manifold lesions which may be met with in war-injuries of the brachial plexus, if attention be directed in the first place to the more important points regarding its surgical anatomy. (Fig. 90.)

A description of the mode of formation and relations of the plexus will be found on p. 159. Speaking surgically, the anterior and middle scalene muscles constitute the chief guides to the cervical portion of the plexus. The roots (anterior rami) of the plexus emerge from behind the lateral border of the scalenus anterior, while the three trunks and their divisions rest upon the scalenus medius. Both these muscles, along with the plexus and the third part of the subclavian artery, are covered by a thin but definite layer of fascia, which is a lateral continuation of the prevertebral layer of deep cervical fascia. This fascia must be divided before the component parts of the plexus can be defined, freed, and separated from one another.

The dissection to expose the upper part of the cervical portion of the plexus, namely, the anterior rami of the fifth and sixth cervical nerves, their union a little external to the scalenus anticus to form the upper trunk and its anterior and posterior divisions, is a comparatively simple matter ; exposure of the lowest trunk, formed by the anterior rami of the eighth cervical and part of the first thoracic nerves requires, on the other hand, a deep and delicate dissection.

The suprascapular nerve, which springs from the lateral border of the upper trunk, 1½ in. above the clavicle, passes downwards, outwards, and backwards to disappear behind the clavicle close to the anterior border of the trapezius. If, therefore, we follow the upper trunk of the plexus towards the clavicle it appears to end in three nerve strands, namely, its two divisions and the suprascapular nerve. The anterior

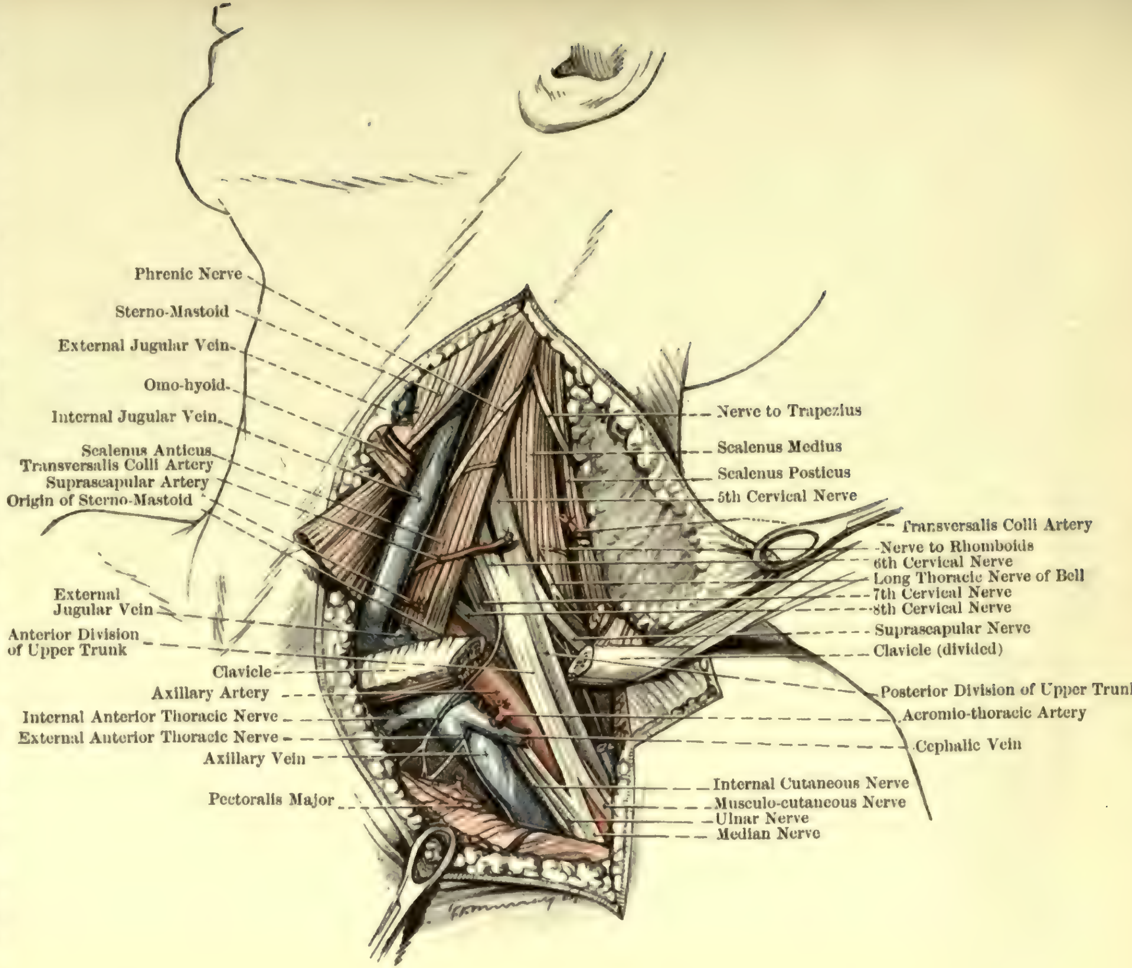


FIG. 90.—Operation for exposure of the whole of the brachial plexus. Incision as in Fig. 91. A flap of cervical integuments reflected backwards; infraclavicular flaps reflected, the one downwards and inwards, the other downwards and outwards. Clavicular origin of sterno-mastoid muscle divided and reflected inwards and upwards; internal jugular vein exposed; external jugular vein divided and ligatured. Clavicular origin of pectoralis major divided and retracted downwards and inwards. Clavicle divided subperiosteally at its centre and the two fragments held well apart. Bridge of periosteum and part of subclavius muscle removed. Costo-coracoid membrane removed and upper border of pectoralis minor freed and retracted downwards, or, if necessary, the muscle divided. Omo-hyoid muscle divided. Transverse cervical and transverse scapular vessels divided and ligatured; also cephalic vein and branches of arteria thoraco-acromialis. Fifth, sixth, seventh, and eighth cervical nerves seen emerging from behind outer border of scalenus anticus; relation of eighth nerve to subclavian artery well seen. The cervical portion of the plexus lies upon the scalenus medius muscle. The fifth and sixth nerves unite to form the upper trunk, which is seen to divide into its anterior and posterior divisions; the former is continued into the axilla as the outer cord of the plexus, which gives off the musculo-cutaneous and the outer head of the median nerves. Arising from the outer border of the upper trunk is the suprascapular nerve, a little above and lateral to which the upper root of the long thoracic nerve is seen just after it has pierced the scalenus medius muscle. The phrenic and descending superficial cervical nerves are seen at the upper part of the dissection

division helps to form the outer cord of the plexus, and furnishes the fibres to the external anterior thoracic nerve, the musculo-cutaneous, and the outer head of the median. Electrical stimulation of this division causes contraction of the upper part of the pectoralis major ; the flexors of the forearm ; the pronator teres, the flexors of the wrist (with the exception of the flexor carpi ulnaris), and the flexor digitorum sublimis. The posterior division helps to form the posterior cord of the plexus ; stimulation of it causes contraction of the muscles inserted into the proximal half of the humerus, with the exception of the supraspinatus and infraspinatus muscles which are supplied by the suprascapular nerve and pectoralis major as noted above ; also contraction of the supinator brevis muscle.

The lowest trunk of the plexus (formed by the anterior rami of 8 C. and 1 T.) lies deeply at the root of the neck, wedged in between the third part of the subclavian artery and the upper surface of the first rib. As shown by Wood Jones, this nerve trunk often takes as large (and sometimes even larger) a share in the formation of the subclavian groove on the rib as does the artery itself. To expose this trunk the third part of the subclavian artery must be freed and retracted downwards and inwards. When this has been done, note that the anterior ramus of the first thoracic nerve joins that of the eighth cervical at the inner border of the first rib just in front of the inner edge of the insertion of the scalenus medius muscle. Note also that both these rami lie in direct contact with the postero-lateral aspect of the cervical pleura.

The anterior division of this lowest trunk conveys fibres to the internal anterior thoracic nerve, to the inner head of the median, and to the ulnar nerve ; hence when stimulated it causes contraction of both pectoral muscles, of the deep layer of muscles of the front of the forearm (flexor digitorum profundus, flexor pollicis longus, pronator quadratus), and of all the intrinsic muscles of the hand supplied by the ulnar nerve. The posterior division helps to form the posterior cord of the plexus, and when stimulated it causes contraction of the extensors of the wrist, fingers, and thumb, and to some extent also of the triceps.

The middle trunk, formed by the anterior ramus of the seventh cervical alone, is smaller than the upper and lower trunks, and is to some extent overlapped by them, so that it does not come fully into view until they have been retracted upwards and outwards and downwards and inwards respectively. The anterior division of this middle trunk helps to form the outer cord of the plexus, and when this division is stimulated it causes contraction of some of the fibres of the pectoralis major, of the coraco-brachialis, of the deep forearm muscles, and of those intrinsic muscles of the hand which are supplied by the median nerve. The posterior division contributes to the formation of the posterior cord

of the plexus, and its stimulation causes partial contraction of the triceps along with contraction of the extensors of the wrist, thumb, and fingers.

Of the supraclavicular branches, the suprascapular has been already referred to; it is a useful guide to the upper trunk. If, along with an injury of the plexus, the muscles supplied by this nerve are paralysed, we know that the lesion involves the upper trunk; and if the rhomboid muscles are also paralysed, we know that the highest root of the plexus is involved, because this nerve springs from the outer border of the anterior ramus of the fifth cervical nerve before it joins the sixth. It emerges from the anterior surface of the scalenus medius a little above the highest root of the nerve to the serratus magnus and passes downwards and outwards upon this muscle for a short distance before it disappears from view by passing beneath the anterior border of the levator anguli scapulæ muscle.

The three roots of the long thoracic nerve spring from the anterior rami of the fifth, sixth, and seventh cervical nerves close to the intervertebral foramina. These roots supply respectively the upper, middle, and lower portions of the serratus magnus muscle. The upper two roots emerge upon the anterior surface of the scalenus medius muscle, while the lowest passes in front of it. All these roots are comparatively slender, so that it is not difficult to understand how an isolated paralysis of the serratus may be met with as a result of laceration, severe bruising, or overstretching of the scalenus medius muscle. Thus formed, the trunk of the nerve descends behind the plexus, which must be retracted downwards and inwards to expose it. While the nerve may be injured along with the plexus as it courses behind it, serratus paralysis as part of the syndrome of a brachial plexus lesion points rather to the lesion having involved the roots of the plexus, and this is all the more indicated if the rhomboid muscles are also paralysed.

While the main root of the phrenic is derived from the fourth cervical nerve, it generally receives a small root from the third and fifth cervicals. In extensive lesions of the brachial plexus, especially when the upper trunk is involved, it is not uncommon to find the phrenic either embedded in scar tissue or completely severed. When the nerve is intact, electrical stimulation of it causes a bulging of the corresponding half of the epigastrium. Paralysis of one half of the diaphragm, the result of injury to the phrenic, is at once detected on X-ray examination by the imperfect descent of the muscle on the paralysed side. Where the nerve descends upon the scalenus anticus muscle beneath the prevertebral fascia it is overlapped by the lateral border of the internal jugular vein, and is exposed therefore when this vein is mobilized and retracted inwards.

The external and internal anterior thoracic nerves supply the pectoral muscles; they spring from that part of the plexus which lies behind the

clavicle, the external nerve from the inner border of the outer cord, the internal from the inner border of the inner cord ; hence the pectoral muscles draw their nerve supply from all the roots which go to form the plexus. These two anterior thoracic nerves come into view in operations on the plexus which call for division of the clavicle and exploration of the upper axilla.

The details of the operative procedures which may be called for in dealing with war injuries of the brachial plexus will vary with the nature and level of the lesion, as well as with its extent and complications. It is necessary in the first place to describe the normal dissection for the exposure of the whole supraclavicular portion of the plexus.

With regard to the position of the patient, the shoulders should be elevated by putting a sandbag between the shoulder blades, and the head placed so as to stretch out the lateral aspect of the neck. A nurse should be detailed to keep the shoulder depressed by pulling on a clove hitch applied to the wrist, the ends of the bandage being sufficiently long to keep her well out of the way of the operator.

There are two incisions which may be regarded as 'normal', namely, the single oblique incision and the L-shaped incision. The former should begin rather above the middle of the posterior border of the sternomastoid muscle and end a little internal to the coracoid process. If it is found necessary to follow the plexus into the axilla, the incision is prolonged downwards as far as may be necessary. (Fig. 91.)

The L-shaped incision is placed with its upper limb parallel, and a little internal to the posterior border of the sternomastoid, while its lower limb runs horizontally outwards a little below and parallel to the middle two-fourths of the clavicle. The writer prefers this latter incision because it gives free access to all parts of the plexus and allows of free removal of scar tissue—an important point when the plexus has been injured by shrapnel or shell-casing, which, besides injuring the plexus, has caused considerable laceration of adjacent structures. An advantage of placing the horizontal limb of the incision below the clavicle is that the resulting cicatrix is less liable to be chafed than it would be if this portion of the incision were placed either above or opposite that bone.

After reflecting outwards the triangular flap of skin and platysma, the posterior border of the sternomastoid is defined. In doing this the lower part of the external jugular vein is freed and divided between forceps. The outer fibres of the sternomastoid are then divided close to the clavicle, so that the muscle may be more thoroughly retracted inwards. This procedure is especially called for when the lowest trunk of the plexus is involved. The deep fascia is now divided along the upper border of the clavicle, and, along with the subjacent cushion of

fat, is dissected upwards and backwards so as to expose the posterior belly of the omohyoid muscle which is freed and retracted, or, if necessary, resected. The transverse cervical vessels are divided between forceps as they pass outwards in front of the plexus. By retracting the sterno-mastoid muscle well inwards the scalenus anticus is exposed and its outer border defined and freed.

The upper trunk of the plexus is now exposed, descending upon the scalenus medius muscle. The two roots of this trunk, formed by the anterior rami of the fifth and sixth cervical nerves, may now be followed upwards and inwards behind the scalenus anticus. Note that the fifth nerve is considerably smaller than the sixth, and that it appears from behind the outer border of the scalenus anticus opposite the transverse process of the fifth cervical vertebra, which corresponds to the level of the lower border of the thyroid cartilage. Care must be taken not to mistake the trunk of the descending superficial nerve for the anterior ramus of the fifth cervical. This mistake is all the more likely to be made, seeing that faradic stimulation of the trunk of the descending superficial cervical nerve may give rise to elevation of the scapula, the result of contraction of the trapezius muscle. This contraction of the trapezius, which is due to an overflow stimulation of the accessory spinal nerve, might easily be mistaken for contraction of the levator anguli scapulæ and rhomboid muscles which are supplied by the fifth cervical nerve. The anterior ramus of the sixth cervical nerve descends in front of the transverse process (carotid tubercle) of the sixth vertebra, against which it is liable to be contused or even lacerated. In lesions of the upper trunk of the plexus it is not uncommon to find that this process has been fractured, in which case it will be found to be enlarged and unduly prominent. If there should be any difficulty in finding the upper trunk, the best plan is to expose the suprascapular nerve just above the clavicle and then to trace it upwards. Immediately below the origin of this nerve the upper trunk divides into its anterior and posterior divisions.

FIG. 91.—To illustrate incision for complete exposure of the brachial plexus.

A clean bullet wound of the neck may cause an isolated lesion of this

upper trunk, which may be either completely divided, embedded in scar tissue, or the seat of a cicatricial neuroma. If the lesion is limited to the upper trunk, its resection may be followed by end-to-end suturing of the anterior rami of the fifth and sixth cervical nerves to the two divisions of the trunk along with the suprascapular nerve. Before, however, the distal stumps can be brought into contact with the fifth and sixth roots, the plexus must be well freed, not only in the neck but downwards behind the clavicle into the axilla. This is done by removing the adipose tissue which surrounds the plexus and is continued down along it behind the clavicle into the axilla. While this fat can be separated to a large extent by the finger, there is beneath it a fascial layer which forms a more immediate covering to the plexus and binds together its various strands. To remove this fascia a clean knife-dissection is called for. The short proximal stump, formed by the anterior rami of the fifth and sixth cervical nerves, must be freed sufficiently to allow the sutures to be introduced. For this purpose the scalenus anticus muscle must be freed and retracted inwards, so that the two roots may be followed in a proximal direction posterior to the muscle. Before this can be done satisfactorily, it is necessary to remove a quantity of fat and one or two deep cervical glands which lie along the lateral aspect of the internal jugular vein, and then to free and retract inwards the vein itself. The opportunity may now be taken to investigate the phrenic nerve as it descends upon the scalenus anticus muscle, covered by a thin layer of prevertebral fascia. This step in the operation is troublesome if the vein is bound down to the muscle by firm adhesions or scar tissue. If the nerve to the rhomboids (posterior scapular) and the nerve to the serratus magnus (long thoracic) have not been involved in the lesion, care should be taken not to injure them at this stage of the dissection. If, on the other hand, they are already involved, the chances are that the anterior rami have been damaged too near the spinal canal to admit of successful end-to-end suture. In this case the only alternative is to anastomose the distal stump into a lateral wedge removed from the anterior ramus of the seventh cervical nerve ; or, if the distal stump is represented by the two divisions of the upper trunk and by the divided suprascapular nerve, one of them may be transplanted into a wedge removed from the lowest trunk (formed by the junction of the anterior rami of the eighth cervical and first thoracic nerves), the others into the seventh nerve as above described. It is a question, however, whether it is wise to injure nerve trunks which have not been involved for the sake of a problematic benefit.

When the lesion is below the fifth and sixth roots and involves the upper trunk along with its two divisions, the clavicle will generally have to be divided in order to ascertain if by freeing and pulling upwards the

axillary portion of the plexus, it is possible to perform a resection followed by end-to-end union. If this is impossible, the operator will generally have to content himself with freeing and incising the injured trunks. If, however, these have been completely severed and it is evident that the freshened stumps could not be approximated after the bulbs have been removed, the latter should be left on and sutured to one another in the hope that by the slow-stretching method they may be removed at a subsequent operation and the freshened ends approximated. If the lesion is still more extensive, the operator will have to consider whether it is worth while doing a lateral anastomosis or a nerve-grafting operation ; in attempting the latter procedure, a graft consisting of several cables must be employed. A two- or three-ply graft of the internal cutaneous nerve of the arm or the cutaneous portion of the musculo-cutaneous nerve of the leg may be utilized. It is also worth while considering whether it might not be possible to make use of the trunk of the descending superficial cervical nerve and its proximal subdivisions.

Exposure of lowest Trunk. Next, the exposure of the lowest trunk of the plexus, namely that formed by the anterior rami of the eighth cervical and first thoracic nerves, must be described. This is done by freeing and tracing the outer border of the scalenus anticus muscle down to its insertion into the scalene tubercle of the first rib. This entails the removal still lower down of the fat and one or two of the lower carotid lymph glands, so as to expose the lowest portion of the internal jugular vein, which must be freed and retracted inwards. In working close to the angle between this vein and the subclavian vein, care must be taken not to wound either the dilated terminal portion of the external jugular vein or the transverse cervical and suprascapular veins just where they open into it. The most likely vein to be injured is the suprascapular, as it is hidden from view by the clavicle. It is important, therefore, to deliberately isolate these veins, and, having divided them between hæmostatic forceps, to displace the proximal stumps inwards along with the lower part of the internal jugular. At this stage of the dissection, care must also be taken not to injure the thoracic duct if it is the left side of the neck which is being operated on. The best way to avoid the duct is to keep the edge of the knife in contact with the structures one intends to expose ; the duct, being very elastic and surrounded by loose fatty tissue, will generally take care of itself, provided, of course, it is not involved in adhesions.

The third part of the subclavian artery is now seen and its pulsation felt as it rests on the first rib immediately external to the anterior scalene muscle. Before the artery can be fully exposed, freed, and mobilized, its sheath, formed by the prevertebral fascia, must be divided. If the vessel be now retracted downwards and inwards, the lowest trunk of the

brachial plexus is brought into view. To expose the two roots of this trunk (8 C. and 1 T.), the outer border of the scalenus anticus must be divided close to the scalene tubercle and the remainder of the muscle, along with the phrenic nerve and the lower part of the internal jugular vein, must be retracted downwards and inwards. The important relations of these two roots, and of their union to form the lowest trunk of the plexus, to the pleura, the subclavian artery, the first rib and the inner border of the scalenus medius muscle have already been referred to.

While extensive lesions of this trunk and its roots are generally fatal owing to their close proximity to the main vessels, there are nevertheless two types of lesions met with which are more or less amenable to operative treatment.

There is the type in which this trunk, either alone or along with the rest of the plexus, has been severely contused between the clavicle and the first rib. In this case the clavicle has usually, though not invariably, been fractured, and one of the fragments has been driven backwards against the plexus, or it is being compressed by excessive callus; or a missile may have been lodged in the root of the neck or upper part of the pleural cavity and given rise to inflammatory thickening and adhesions around and between the constitutents of the plexus, especially between it, the rib, the pleura, and the subclavian artery. In these diffuse types of injury the indications are to remove all cicatricial tissue and compressing bone, and to make a clean dissection, if necessary, of the whole plexus. Wherever the sheath is much thickened to form neuromatous swellings, it should be either incised or, still better, dissected away so as to expose the nerve bundles.

In many cases in which the plexus has been contused, improvement may be brought about by non-operative methods. In others, again, operation is called for either on account of a residue of persistent paralysis or on account of severe and persistent neuralgia. For example, in a patient who suffered from severe brachial neuralgia, the writer was obliged to operate immediately after the wound above the clavicle had healed. The skiagram showed a cubical piece of shell-casing situated behind the apex of the lung in the neighbourhood of the posterior part of the first intercostal space. The neuralgia was most intense along the sensory distribution of the lowest trunk of the plexus. The adhesions involved more especially the lower end of the internal jugular vein, the lower part of the scalenus anticus muscle, the subclavian artery, the cervical pleura, the two lowest roots of the plexus, and the trunk formed by their union. In freeing the lower end of the internal jugular vein and the scalenus anticus muscle, the cervical pleura was opened into. The subclavian artery was freed and retracted downwards and inwards, after which the lowest trunk and its two roots were separated from the

pleura and the inner border of the first rib, to both of which they were fixed by adhesions. With the subclavian artery retracted downwards and inwards, the finger was introduced into the opening made into the cervical pleura, and, after separating the adherent apex of the lung, an irregularity was felt towards the posterior part of the inner border of the first rib, this portion having been injured by the missile. As no foreign body could be felt, about 1½ in. of the first rib was resected well posterior to the subclavian artery. Before the resection, the insertion of the scalenus medius muscle was detached from the rib and the latter was freed from the parietal pleura. After removing the piece of rib, the finger could be passed behind the cervical pleura so as to separate this membrane as far back as the tubercle. When this had been done the missile could be felt behind the thickened pleura a little below the posterior part of the inner border of the first rib. In detaching the scalenus medius from the first rib, care should be taken to keep close to the bone, so as not to injure the nerve to the serratus or one of its roots, especially the lowest.

With regard to the opening which had been accidentally made into the cervical pleura, it was not possible to close it with sutures, as the edges of the opening were adherent to the internal jugular vein and to other important structures which could not be included in the sutures. In the treatment of such a complication the main point, of course, is to prevent suction of air into the pleural cavity. This is most conveniently done by carefully plugging down to the opening with a strip of iodoform gauze and then stitching the deep structures and skin as closely as possible round the end of the gauze which is brought out through the skin wound. A large dressing should be firmly fixed in position by a carefully applied bandage. When the gauze packing is removed, which should not be until the eighth or tenth day, the small opening left in the skin wound is completely closed by means of a suture. As long as the temperature remains normal, or nearly so, the slight pleuritic effusion which results from the operation may be allowed to absorb.

The type of lesion of the lowest trunk of the plexus next to be referred to is of special interest both as regards its nature and its mode of production. This lesion is characterized by the presence of a localized neuromatous thickening of the anterior ramus of the first thoracic nerve, just where it arches over the sharp inner border of the first rib to join the anterior ramus of the eighth cervical nerve to form the lowest trunk of the plexus. The history of such a condition is that the patient had received a gunshot wound, that the bullet had traversed the upper part of the chest and the root of the neck, and that in doing so it had passed through the inlet of the thorax. The disruptive force, which radiated in all directions from the missile, caused that portion of the first thoracic nerve which joins the eighth cervical, to be severely contused by being

driven violently against the sharp inner border of the first rib, the result being that some of the fibres were cut completely across, while the sheath of the nerve itself remained almost intact, though thickened. A fibrous neuroma about the size and shape of a large grain of wheat developed in the substance of the lowest trunk exactly opposite the edge of the rib, that is to say, just where the first thoracic joins the eighth cervical nerve. The writer has met with two very typical examples of this condition. The symptoms are essentially the same as those which are met with in that particular type of brachial neuralgia and paresis of hand muscles which results from the gradual pressure of the inner border of the first rib upon the branch of the first thoracic as it ascends over, and is, as it were, stretched across the inner border of the first rib to join the eighth cervical nerve.

With regard to the treatment of this localized neuroma, non-operative measures should be given a fair trial, and if no improvement results after three or four months, the lowest trunk of the plexus and its two roots should be exposed in the manner just described, and the neuroma removed. Should the lesion, however, prove to be more diffuse, the involved portion of the nerve should be thoroughly freed from adhesions and its thickened sheath excised.

From the operator's point of view these cases are particularly fascinating as the track of the bullet need not necessarily be in the immediate neighbourhood of the lesion, and therefore the dissection, although a deep and delicate one, is not complicated by the presence of scar tissue and adhesions.

Exposure of the entire Plexus. To complete the operative treatment of brachial plexus injuries it is necessary to refer to the procedure to be adopted when the lesion has involved the portion of the plexus which lies behind the clavicle along with one or all of the cords. Such lesions are liable to occur when the missile has traversed the axilla as well as the root of the neck, or when the clavicle has been fractured and the ends driven backwards against the plexus, or when the plexus is compressed between a mass of redundant callus and the first rib. There is another type of case, namely where the shoulder has been forcibly depressed, with the result that the plexus has either been contused against the first rib or ruptured in the neighbourhood of its roots. In such cases the upper two roots may be torn across, while the lower trunk of the plexus is at the same time severely contused between the clavicle and the first rib. The indication here is to make a complete exposure of the whole plexus, and, having ascertained the exact nature of the lesion, to deal with it accordingly. Unfortunately in many cases little or nothing can be done ; but while this is the case, an exploratory operation should be undertaken in practically all cases, because it is often impossible to foresee from clinical evidence alone which cases are hopeless

and which can be benefited. Not infrequently one discovers that the paralysis is due to compression, and by relieving this, rapid and marked improvement frequently takes place. The best incision for exposure of the whole plexus is the angular one already mentioned, with the addition of a third limb which extends downwards from the horizontal limb along the interval between the pectoralis major and the deltoid muscles.

The middle two-fourths of the clavicle is exposed and its muscular attachments and periosteum are freed from its middle third. It is then divided at its centre with a Gigli saw, but before doing so, it is advisable to drill the two holes through which the wire is to be threaded for the subsequent suturing of the fragments. These holes should pass obliquely through the fragments, so as to avoid irritation of the plexus by a wire on the postero-inferior aspect of the bone. If the plexus is being pressed upon by callus, the redundant portion should be removed at this stage, and in some cases it may be necessary to resect the fractured area and to remove a comminuted fragment which has been displaced backwards.

After dealing with the clavicle, the next step is the removal of the subclavius muscle, the costo-coracoid membrane and the fascia which surrounds and binds together the axillary vessels and the component parts of the plexus. To obtain sufficient access for this purpose it is advisable to retract the clavicular portion of the pectoralis muscle (which has already been separated from the clavicle) well backwards and inwards, taking care to dissect out and preserve the external anterior thoracic nerve if it has not been destroyed. The anterior fibres of the deltoid, which have also been detached from the clavicle, are retracted backwards and outwards, so as to expose the insertion of the pectoralis minor into the coracoid process. The upper border of this muscle is now freed and the muscle itself either retracted well downwards, divided, or partly resected, according to the extent of the lesion. There is no object in preserving the muscle if the internal anterior thoracic nerve is destroyed. During this part of the operation, the fragments of the clavicle must be well retracted by means either of two bone hooks, or of two strips of sterile bandage. (Fig. 90, p. 159.)

The difficulty, and it is frequently a very real one, which the surgeon is most likely to be confronted with, arises from the amount and density of the scar tissue and the manner in which it has implicated not only the nerve cords, but also the vessels, especially the axillary vein and its tributaries. The safest procedure is to begin the deep dissection by exposing the axillary vein, and the best way to do this is to follow upwards the cephalic vein to its entrance into it, and then to free the whole axillary vein so that it may be retracted well inwards. The axillary artery is next exposed and mobilized, after which the cords of the brachial plexus are dealt with. The outer cord is the most superficial, and as it descends

it comes to lie in front of the axillary artery. Behind and lateral to this cord is the posterior division of the upper trunk which helps to form the posterior cord. By tracing the latter downwards the commencement of the musculo-spiral nerve will be reached. The inner cord and its branches are exposed by retracting the axillary artery outwards and the corresponding vein inwards. The two heads of the median are easily recognized by their relation to the axillary artery, which is embraced by them. Not infrequently the two heads of the median unite at a much lower level, while occasionally the fibres of the musculo-cutaneous nerve run along with its outer head and thence in the median itself to leave it again in the upper third of the arm. The commencement of the ulnar nerve lies deep to the inner head of the median.

The nerve lesions which may be met with in the clavicular and sub-clavicular regions are very varied. Moreover, they are very liable to be complicated by the presence of an aneurism, either true, false, or arterio-venous, and the operation may be rendered still more difficult by the fact that the axillary artery or vein, or both, may have been previously ligatured for the arrest of a primary or secondary hæmorrhage, and should the wound have suppurated, as not infrequently happens, the nerves may be so embedded in scar tissue that their isolation is wellnigh impossible. No definite rules can be laid down for the treatment of such complicated cases. Patience, perseverance, and, best of all, a thorough knowledge of the anatomy of the region are the chief desiderata ; indeed, in some cases the operation will have to be abandoned, and the surgeon must then console himself with the fact that he has given the patient a chance, and, while he has not been able to do him any good, he has at any rate done him no harm. Sometimes the operation, while it may have done nothing to help the paralysis, will be found to have relieved pain, and to have diminished the trophic disturbances in the hand, and to have improved the circulation of the limb.

If a resection and suture of one or more of the nerves has been performed, it will generally be necessary to divide the whole pectoralis major muscle so as to enable the distal portion of the injured nerve or nerves to be sufficiently freed for the purpose of upward traction being applied to them.

After the nerves have been dealt with and after all bleeding has been very carefully arrested, the clavicle is wired.

With regard to the muscles, it is not necessary to completely restore the attachments of the muscles or to suture the whole of the divided portion of the pectoral muscle ; indeed, if this be done and the arm kept bandaged to the side for several weeks, there is a risk that abduction would be permanently restricted.

When the dissection has been an extensive one, it is generally advis-

able to introduce a drainage-tube to provide for dependent drainage through a stab wound, placed posteriorly.

In applying the dressing, the arm may be bandaged to the chest if the deltoid muscle is not paralysed, and the bandage should be made to grip the elbow in such a way as to produce the maximum elevation of the shoulder ; if, on the other hand, the deltoid is also paralysed, the arm should be abducted at the same time as the shoulder is elevated, and to do this efficiently a plaster-of-Paris bandage is much better than a splint : in applying the plaster bandages, a Hawley table is a great advantage. If the operation has involved a dissection of the root of the neck, the head should be adducted towards the shoulder. The elbow should be kept in the flexed position, and if the posterior cord of the plexus is involved, the wrist and hand must be kept in the position described under lesions of the musculo-spiral nerve.

NERVES IN MIDDLE THIRD OF AXILLA

For descriptive purposes we may include in this dissection operations performed for lesions of any of the large terminal branches of the brachial plexus situated between the lower border of the pectoralis minor and the upper border of the latissimus dorsi. To obtain proper access to the nerves in this part of their course, the axilla must be laid freely open from the front.

The arm is abducted to a right angle, and, to enable it to be at the same time rotated outward as much as possible, the elbow should be slightly elevated on a sandbag. The shoulder on the affected side should be brought well towards the edge of the operating table.

The incision, which is begun immediately below and internal to the coracoid process, is carried across the pectoralis major and the anterior fold of the axilla so as to meet the arm opposite the inner border of the coraco-brachialis along which it may be continued in a distal direction as far as necessary. The cephalic vein, which is exposed in the subcutaneous tissue at the upper end of the wound, is freed and displaced laterally. The fibres of the lower two-thirds of the pectoralis major are divided transversely so as to expose the subpectoral fascia which forms the immediate roof of the axilla. When, as so often happens, the missile which has injured the nerve or nerves has traversed the axilla, this fascia is generally thickened and scarred in such a way as to bind down the pectoralis major to the subjacent biceps and coraco-brachialis muscles. After dissecting away this fascia, the inner border of the coraco-brachialis is defined and freed in an upward direction as far as the coracoid process, and downwards into the arm. In doing this, forceps are applied to one or two vessels which pass between the muscle and the axillary vessels. After these vessels have been secured, the muscle is retracted outwards,

when the median nerve will be at once exposed lying antero-external to the axillary artery. The internal cutaneous nerve and the axillary vein are also freed and retracted inwards, the axillary artery being then fully exposed. The freeing and retracting of these structures is a perfectly simple matter distal to the lesion, and this should always be done as a preliminary measure, so that the relation of the injured nerve to the axillary artery may be clearly defined before any attempt is made to free the injured portion.

The next step in the dissection is to expose the vessels and nerve trunks above the lesion. To do this, the coraco-brachialis must be followed and freed right up to its origin from the coracoid process, and the lower border of the pectoralis minor must also be defined by dividing the fascia along it, after which the muscle can be retracted upwards and inwards. In dealing with the muscles the operator must remember the important structures which are closely related to them. For example, in freeing the upper part of the coraco-brachialis, descending branches of the acromio-thoracic vessels will be divided, and a sharp look-out must be kept for the musculo-cutaneous nerve, which enters the substance of the muscle about one inch below the tip of the coracoid, the nerve having just previously given off its motor branch to supply that muscle. If the scar tissue has involved the muscle itself, some difficulty may be experienced in isolating the musculo-cutaneous nerve, and not infrequently it will be found that the lesion has extended upwards so as to involve the outer cord of the plexus, and along with it the outer head of the median which lies in close contact with the lateral aspect of the axillary artery. The distance between the origin of the musculo-cutaneous nerve from the outer cord of the plexus and its entrance into the substance of the coraco-brachialis is only about an inch to an inch and a half, so that a complete lesion of the musculo-cutaneous above the muscle generally entails a resection of the lowest part of the outer cord along with the commencement of the outer head of the median and the musculo-cutaneous nerves. In order to obtain sufficient access for this purpose, it is almost always necessary to divide completely the pectoralis minor and then to free the axillary vessels higher up so that they may be more thoroughly retracted inwards. Before this can be done, the long thoracic artery is divided and the axillary fat dissected inwards. When the outer head of the median nerve is followed downwards, it will be found to join the inner a little below where the musculo-cutaneous nerve enters the coraco-brachialis muscle, that is to say, a little above the upper border of the tendon of the latissimus dorsi. One of the main difficulties in this dissection is the close relation of the nerves to the large veins. Troublesome bleeding not infrequently occurs from the venae comites of the brachial artery, which pass up into the axilla and

generally open into the axillary vein somewhere between the lower border of the pectoralis minor and the upper border of the latissimus dorsi. It is in this situation that they are so closely related to the musculo-cutaneous, and especially to both heads of the median nerve. Sometimes it will be necessary to resect a portion of the axillary vein. In this case the cephalic vein becomes the most important channel for the return of blood from the upper extremity; hence care should be taken not to wound this vein in making the incision through the skin and subcutaneous tissue.

After the median nerve, along with its two heads, and the musculo-cutaneous nerves have been dealt with, the ulnar nerve should be examined. It is exposed by thoroughly freeing the axillary vein and retracting it either inwards or outwards, whichever is found to be the most convenient. Usually the best plan is to divide between forceps, close to their termination, the veins which proceed from the inner wall of the axilla to join the axillary vein, and then to retract the latter outwards along with the artery and the nerves already mentioned. If there is much scar tissue, the divided pectoralis major will have to be retracted well inwards, so that the fatty contents of the axilla may be freed from the vein and displaced inwards towards the chest. The intercosto-humeral and the lesser internal cutaneous nerves may be divided. If the ulnar nerve be bound down to the posterior wall of the axilla by scar tissue, it may be necessary to divide the subscapular artery close to its origin, just as is done in clearing out the axilla in cases of malignant disease of the breast. The long subscapular nerve (nerve to the latissimus dorsi), which is closely related to the subscapular vessels, must be sought for and preserved if possible.

The ulnar nerve, having been completely freed, is now followed upwards to its origin from the inner cord of the plexus a little below the pectoralis minor. If the ulnar is involved close to its origin, the inner head of the median is liable to be injured as well, and if a resection is necessary, both nerves may have to be sutured to the inner cord. The internal cutaneous nerve may be disregarded, unless there is a possibility that it may be required as a graft.

The musculo-spiral nerve is seldom involved alone at the level of this dissection. It is best exposed in the first instance below the lesion, by the same dissection as that to expose the ulnar nerve, along with which it is frequently involved. The ulnar, along with the axillary vein, is retracted well inwards, while the artery, the median and musculo-cutaneous nerves are retracted outwards along with the coraco-brachialis muscle. The musculo-spiral is now seen at the floor of the wound, where it rests on, and may be firmly adherent to, the subscapularis muscle. Immediately external and parallel to the musculo-spiral is the circumflex

nerve which curves dorsally across the lower border of the subscapularis between it and the upper border of the latissimus dorsi, these two muscles forming the upper and lower boundaries respectively of the quadrilateral space through which the nerve leaves the axilla. This nerve is frequently involved along with the musculo-spiral, and, like the ulnar, it may be firmly adherent to it. In freeing it from scar tissue it may be impossible to avoid injuring the posterior circumflex vein, and sometimes even the artery may have to be divided. Another difficulty is that the nerve has such a short course that only a limited portion of it can be resected with any hope of bringing the ends into contact. In freeing the musculo-spiral in the proximal direction, the lowest subscapular nerve may have to be sacrificed, but the upper and middle (long) subscapulars, which supply respectively the subscapularis and latissimus dorsi muscles, can frequently be preserved. In following the musculo-spiral distally its internal cutaneous branch may be ignored, but the upper branches to the triceps which come off at, or a little above, the lower border of the latissimus dorsi should be looked for and, if possible, preserved from injury. If one or more of the other branches of the plexus has to be resected as well as the musculo-spiral, it is important to suture the latter first.

The operator must not hesitate to remove, if possible, all scar tissue from the axilla. This should be done not only to prevent its readhesion to the nerves, but with the object also of obtaining free movement at the shoulder-joint.

If the pectoralis minor muscle has not been involved in scar tissue it should be resutured, as also should the divided portion of the pectoralis major, any scar tissue it may contain having been previously dissected away. Interrupted sutures of 21-day iodine catgut should be used for this purpose. It is, however, a matter of little or no importance if the pectoral muscles can only be very imperfectly sutured. The deficiency in the lower part of the greater pectoral is to a large extent compensated for by hypertrophy of the clavicular fibres. This is well seen after the radical operation for cancer of the breast.

It should be remembered that the large nerves of the axilla, like the axillary vessels, are taken off the stretch by adducting the arm, so that the ends of a divided nerve which are some distance apart when the arm is abducted to a right angle may come together readily when the arm is well adducted. To suture the nerves, however, with the arm adducted, the operator must stand above the patient's shoulder and look down into the wound. Another point to bear in mind is that the arm should not be abducted for the purpose of removing the stitches, and the use of a rubber or gauze drain should be avoided. The wound should be rendered as dry as possible before closure. Drainage must be provided

for by allowing the wound to gape a little at one or possibly two places between the sutures, all of which should be interrupted. If there is reason to suspect a good deal of oozing, freer drainage can be got by passing several strands of catgut through a buttonhole opening made through the posterior wall of the axilla, in the interval between the subscapularis and the teres major muscles just medial to the long head of the triceps, care being taken to avoid the subscapular artery and its dorsal scapular branch. As there is sometimes a good deal of serosanguineous discharge, it is well to apply a large absorbent dressing, which should include the whole of the neck and chest as well as the whole upper extremity except the hand.

The bandage should be applied so as to maintain the arm adducted across the chest, while the elbow is kept flexed by means of a Jones double-gutter elbow splint bent to the necessary angle. A long cock-up splint of proper pattern (see p. 185) must also be applied to the hand in cases in which the musculo-spiral nerve has been involved. When the median and ulnar nerves have been sutured, the wrist should be held palmar flexed by means of a bent single gutter splint applied to the back of the forearm and hand.

Combined Lesions of the Nerves and Vessels of the Axilla. While the blood-vessels are sometimes found to be injured along with the nerves, it must be confessed that such combined lesions are much less frequently met with than one would expect from the very close relation of the nerves to the axillary vessels. No doubt one reason is that many soldiers who have received such injuries succumb to hæmorrhage. Nevertheless, among the patients who reach the orthopædic centres, one sees many cases of gunshot injury to the main nerves in the axilla in which the vessels have escaped in a most remarkable manner. The artery escapes more frequently than the vein, due no doubt to the greater thickness of its walls and to its greater elasticity. In some cases one or both of the main vessels, or one of the large branches, has been ligatured to arrest the primary hæmorrhage. In such cases the subsequent operation on the nerves is rendered difficult in consequence of the abundance of dense scar tissue which is often found in the neighbourhood of the injury. In other cases the nerve injury is complicated by the presence of a pulsating aneurism in the axilla, either of the true or false variety, and sometimes arterio-venous in type. In other cases again, there is a firm oval swelling which does not pulsate, and which is found to be an organized hæmatoma.

In all these cases two or more of the nerves are liable to be involved, the lesion being complete in some and partial in others ; in the latter case the symptoms are generally due to the nerve being stretched and spread out as it courses over the wall of the sac. Peripheral pain, along with partial paralysis and trophic lesions, are common symptoms.

The following operation which the writer performed in a case of multiple nerve lesions of the axilla complicated with aneurism may be taken as an example of the kind of procedure to be adopted. There was a thick-walled, oval, pulsating aneurism, the size of a hen's egg, its centre being situated at the level of the lower border of the subscapularis muscle. The incision employed was the same as that above described, except that more room had to be got by the addition of a second incision at right angles to the main one which followed the line of the axillary vessels. This second incision crossed the axilla a little medial to the junction of the arm and chest. After the flaps had been reflected, the sternal fibres of the pectoralis major and the subpectoral fascia were divided transversely until the pectoralis minor was exposed. The axillary vein and median nerve were then freed below the aneurism and retracted outwards along with the coraco-brachialis muscle. The ulnar was retracted inwards. The lower part of the axillary artery was then exposed and traced upwards to the aneurism. The next step consisted in freeing the pectoralis minor, which was retracted well upwards. The axillary fat was then removed from the upper part of the axilla, the intercosto-humeral nerve divided, and forceps applied to one or two unimportant branches of the axillary vessels. This enabled the axillary vein to be freed and separated from the axillary artery above the level of the lesion. The artery was then isolated and clamped immediately above the aneurism, and a second pair of forceps was applied to the vessel immediately below the aneurism. The securing of the artery as close above and below the aneurism as possible is an essential step in the operation and one which should be carried out at as early a stage as possible ; indeed, it is the primary object of what may be regarded as the first stage of the operation. The artery having been controlled, the median nerve, along with its two heads, and the ulnar nerve were then carefully dissected off the anterior wall of the sac, while the musculo-spiral was exposed on the proximal side of it. When freed, the two former nerves were found to be so attenuated and flattened that little else than their sheaths remained.

The anterior wall of the sac was now laid freely open and some old laminated clot rapidly removed, when free, but not alarming, bleeding took place from two openings in the wall of the sac. The bleeding was arrested by clamping the portions of the sac containing these openings with strong artery forceps. The remainder of the clot was then removed from the sac, partly with the finger and partly with a sharp spoon. The sac was found to extend for a considerable distance upwards behind the vessels, between them and the subscapularis muscle. After the anterior wall of the sac had been cut away, the axillary artery was ligatured where it was clamped immediately above and below the aneurism. The

posterior wall of the sac was so adherent to the deeper structures that only a portion of it could be removed; the remainder was firmly adherent to the musculo-spiral nerve; indeed, the latter actually formed part of the wall of the sac. The circumflex nerve was not identified. The lowest subscapular nerve was preserved, but the middle (long) subscapular was involved in the sac. The subscapular artery was ligatured, and the posterior circumflex was certainly one of the vessels opening into the sac.

The final steps of the operation consisted in the resection of 1½ in. of the median and ulnar nerves and suture. Fortunately the musculo-spiral gave a fairly good response to the faradic current so that it was not necessary to interfere with it. The treatment of the wound was the same as that described in the previous operation. The ulnar nerve has now completely recovered, and the median nearly so.

NERVES IN THE LOWER THIRD OF THE AXILLA AND PROXIMAL HALF OF THE UPPER ARM

All the terminal branches of the three cords of the brachial plexus are so closely related to the main blood-vessels of the axilla and upper half of the arm that for descriptive purposes and to avoid repetition they may with advantage be considered together, especially as the lesion may involve two, or even more, of the nerves. The chief nerves to be considered in this region are the *median*, the *ulnar*, and the *musculo-spiral*. All these nerves are best exposed by the normal incision employed for exposure of the lower half of the axillary artery and the upper half of the brachial. The incision begins at the apex of the axilla opposite the medial border of the coraco-brachialis, which corresponds to the junction of the anterior and middle thirds of the outer wall of the axilla. From this point it is carried down along the inner border of the muscle as far as may be necessary. Should it be found necessary later to trace the nerve still higher in the axilla, the incision may be best extended upwards by carrying it along the free border of pectoralis major. At the upper part of the incision the axillary fascia is exposed and below this the deep fascial envelope of the arm. Through this fascia the internal cutaneous nerve can usually be seen coursing along the anterior aspect of the basilic vein. The deep fascia should be incised along the inner border of coraco-brachialis, instead of directly over the neuro-vascular bundle. The internal cutaneous and basilic vein are both freed and retracted backwards. The vein is liable to be wounded accidentally if the incision penetrates too deeply just posterior to the nerve. The inner border of the coraco-brachialis muscle is then freed and retracted forwards and outwards. In doing this a few muscular branches of the brachial artery, along with their companion veins, are divided and ligatured. The median nerve is now exposed lying in contact with the anterior aspect of the

brachial artery. When it has been freed in an upward direction, its two heads will generally be found to join and embrace the artery about the level of the upper border of the latissimus dorsi, which may be regarded as the upper limit of the dissection we are now considering.

The next step in the dissection is the exposure of the ulnar and musculo-spiral nerves. To lay bare the *ulnar*, the basilic vein may be retracted either forwards or backwards, when the nerve will be found lying immediately posterior to the axillary and brachial arteries. Like the median, it gives off no branches either in the axilla or the upper arm, so that it is easily and rapidly freed in both directions. (Fig. 92.)

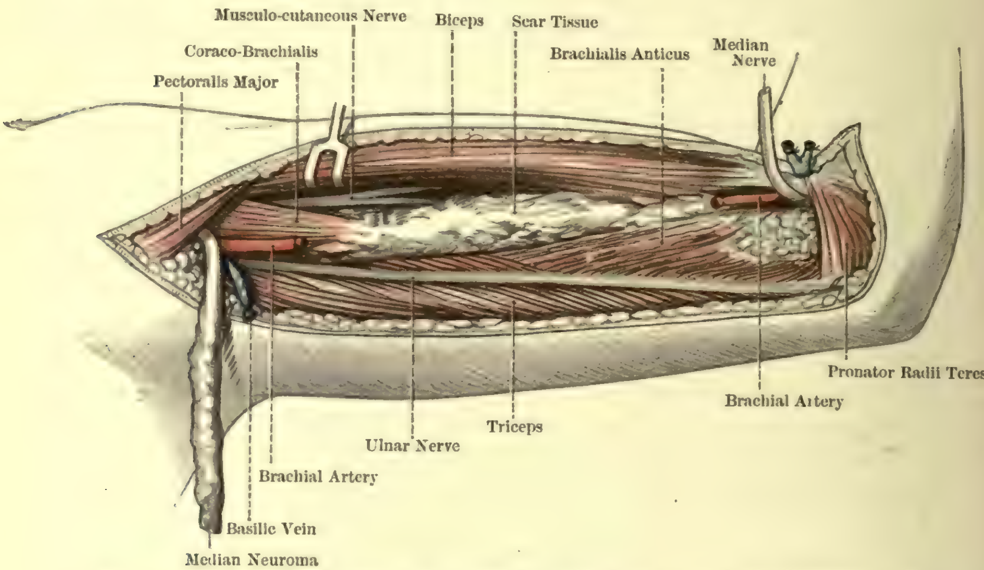


FIG. 92.—Operation for lesion of median and ulnar nerves in the middle of the arm. Median involved in mass of scar tissue at insertion of coraco-brachialis and artery thrombosed in middle third of arm.

If it be a lesion of the *musculo-spiral* with which we have to deal, two methods of approach are available. In the one, the main vessels, along with the internal cutaneous, the median, and the ulnar nerves, are retracted inwards and backwards; while in the other, these structures are retracted in the opposite direction, namely, forwards and outwards. The writer desires particularly to draw attention to the great advantage of the former over the latter method. It will be remembered that the musculo-spiral nerve takes an outward direction as it courses distally behind the humerus to enter the musculo-spiral groove. If the lesion be situated either in the lower part of the axilla or in the proximal half of the arm, the incision should be precisely the same as for exposure of the

median nerve. The musculo-spiral is first exposed above the lesion, that is to say, where it lies behind the axillary artery upon the tendon of the latissimus dorsi, close to its insertion. Here it is readily exposed by retracting the coraco-brachialis muscle and musculo-cutaneous nerve well outwards, while the main vessels, along with the nerves already mentioned, are all retracted backwards and inwards. To follow the nerve as far as

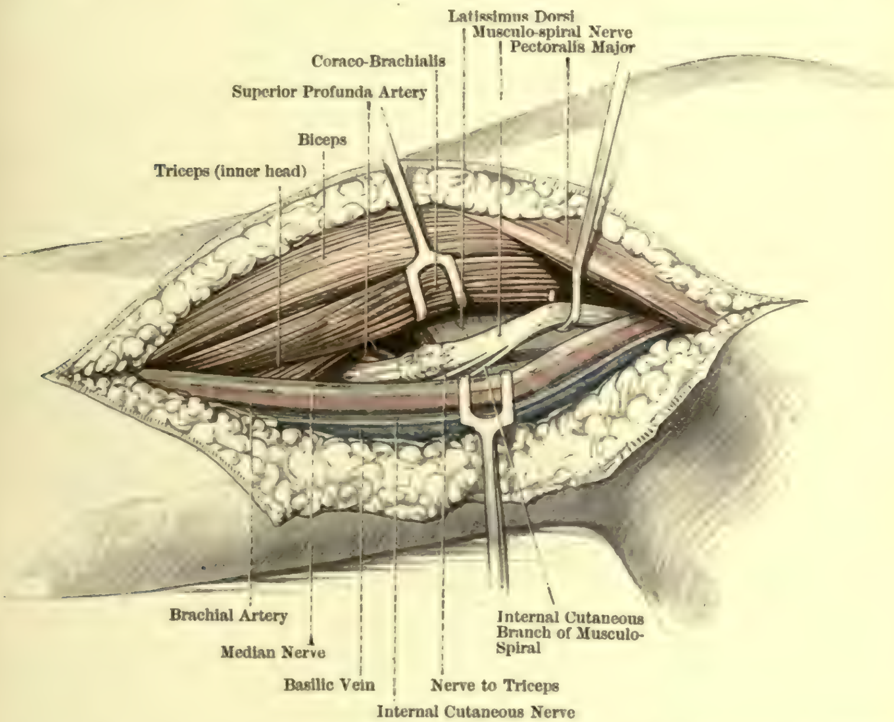


FIG. 93.—Operation for a neuroma of musculo-spiral (N. radialis) in upper third of arm, immediately below the branches to the triceps. Note that the median nerve and main vessels have been retracted inwards and backwards.

the musculo-spiral groove, the dissection is continued downwards deeply between the brachial artery and the coraco-brachialis muscle. (Figs. 93 and 94.) The artery, along with its venæ comites and the basilic vein, and also the median nerve are freed in a distal direction as far as the insertion of the coraco-brachialis ; if they are now retracted well inwards and backwards, the superior profunda vessels will come into view so that they may be divided between forceps and ligatured, a step which greatly facilitates the following of the nerve into the upper part of the musculo-spiral groove. In a certain proportion of cases (one in five, according to Quain) the musculo-cutaneous nerve leaves the outer head of the median at

a much lower level than usual, even as low as the insertion of coraco-brachialis. This arrangement makes more difficult the exposure of the musculo-spiral by inward retraction of the brachial vessels and nerves.

The branches which arise from the musculo-spiral in this dissection are the internal cutaneous, the ulnar collateral to the inner head of the triceps, and branches to its long and outer heads. All these branches come off close together at the level of, or a little below, the lower border of the latissimus dorsi ; by careful dissection, they can generally be preserved intact when the lesion is placed a little above the musculo-spiral groove, and, if necesssary, they can be traced up from the main nerve as a separate

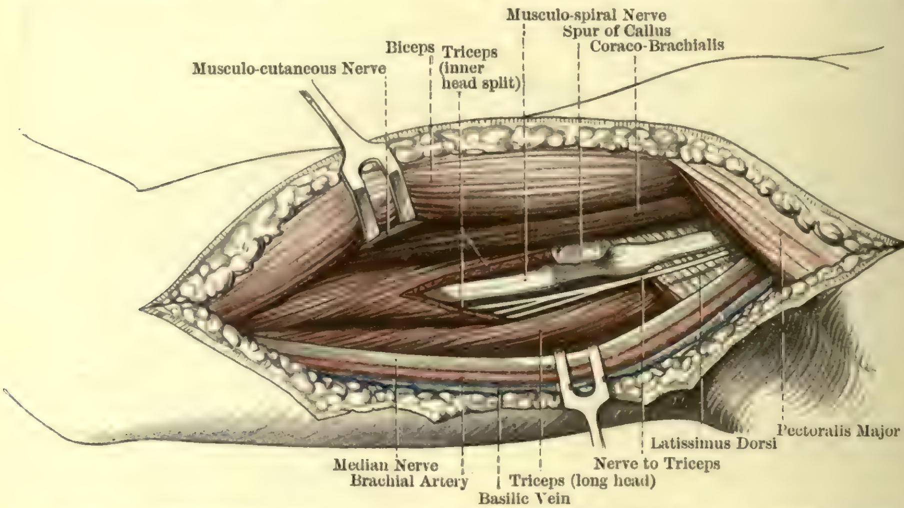


FIG. 94.—Operation to free the musculo-spiral (N. radialis) from a spur of callus. Note the bulbous swelling immediately above the compressed portion of the nerve. Lesion exposed by retracting the median nerve and main vessels backwards and inwards. Medial head of triceps divided and radial nerve traced distally along the musculo-spiral groove. Branches to triceps freed from the injured portion of the nerve.

bundle high up into the axilla. The nerve can be followed for a considerable distance along the musculo-spiral groove without altering the position of the limb and, what is more important, without dividing the outer head of the triceps. All that is necessary is to divide the upper fibres of the inner head of the triceps close to the humerus. The superior profunda artery has already been secured, but forceps will again have to be applied to the companion vein at a lower level. In this way the musculo-spiral may be exposed and freed from the upper border of the latissimus dorsi down to the middle of the groove, and this exposure will admit of an end-to-end suture after resection of $1\frac{1}{2}$ in. of the nerve, provided the arm is adducted.

MUSCULO-SPIRAL NERVE IN THE LOWER HALF OF THE ARM AND ITS TRANSPOSITION IN DIFFICULT CASES

This operation involves the dissection to expose the nerve from the lower end of the musculo-spiral groove to its bifurcation, which takes place opposite the external condyle of the humerus under cover of the supinator longus muscle. In the upper third of the dissection, the nerve lies immediately behind the external intermuscular septum; in the middle third it lies in the substance of the septum; while in the lowest third it is separated from the septum by the supinator longus and extensor carpi radialis longior muscles. The incision to expose the nerve should, therefore, cross the septum very obliquely, its upper extremity being placed a little behind the insertion of the deltoid and its lower extremity midway between the biceps tendon and the external epicondyle of the humerus. The median cephalic vein is divided between forceps at the lower end of the incision, while at its middle the proximal and distal dorsal cutaneous branches of the musculo-spiral are exposed. The former, which courses downwards and forwards in front of the septum, is the smaller, and may be ignored; the latter, which takes a dorsal direction, is more important as it serves as a useful guide to the musculo-spiral. By tracing this cutaneous branch in the proximal direction it will be found to pierce the external intermuscular septum, and by following it upwards in the substance of the septum its origin from the musculo-spiral nerve will be reached. (Fig. 95.)

Another method of finding the nerve is to expose the anterior border of the supinator longus muscle at the lower end of the incision, and then to free it in an upward direction so that it may be well retracted, after which the nerve will be found close to its bifurcation, deep down in the interval between this muscle and the brachialis anticus. During this step of the dissection, branches of the radial recurrent vessels must be secured and ligatured. The operator is warned against searching for the nerve in the first instance opposite the middle of the wound, because in this situation there is practically no guide to the interval between the supinator longus and the brachialis anticus muscles, and there is a distinct likelihood that the nerve will be missed owing to the dissection being carried into the substance of the brachialis anticus instead of between it and the supinator longus. The best plan, therefore, is to begin by exposing the nerve either at the upper or at the lower part of the wound. (Fig. 95.)

The main trouble in the operation is, however, generally due to the dense scar tissue which often surrounds the nerve and binds it firmly down to the site of an old fracture of the humerus. In dissecting away this scar tissue a good deal of inconvenience may be caused from the

bleeding of the superior profunda vessels which are very closely related to the musculo-spiral nerve.

After resecting the injured portion of the nerve, it will generally be necessary to prolong the incision into the antecubital fossa in order completely to free the nerve down to its bifurcation. During this step of the operation it will generally be necessary to sacrifice the nerve to the supinator longus, and sometimes also that to the extensor carpi radialis longior. Every attempt should, however, be made to preserve the branch to the extensor carpi radialis brevior which arises from the commencement of the posterior interosseous. The small branch to the

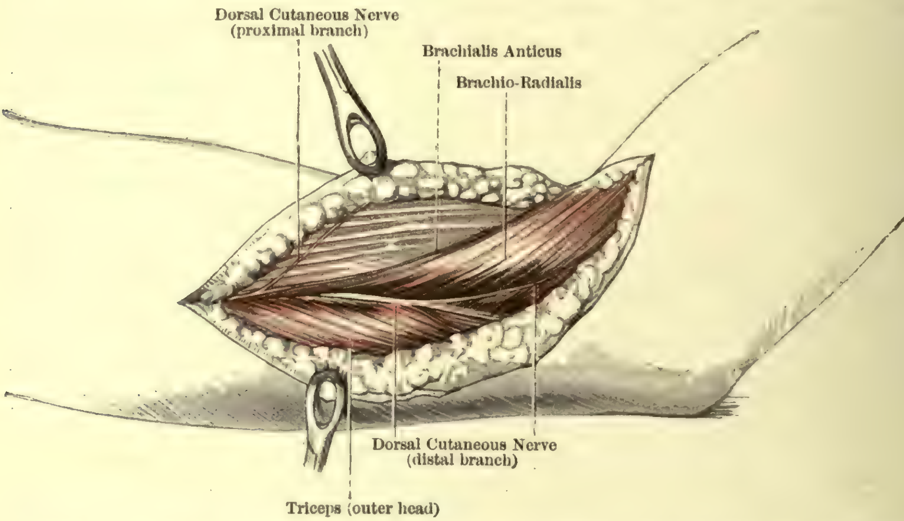


FIG. 95.—First stage of operation to expose the musculo-spiral (N. radialis) in lower third of arm. At the upper part of the dissection the superior and inferior *dorsal* cutaneous branches of the musculo-spiral are seen emerging from the external intermuscular septum. The interval between the brachialis anticus and the supinator longus (brachio-radialis) muscle is defined by defining the antero-medial border of the latter muscle at the bend of the elbow and then tracing it upwards.

brachialis anticus is of no importance, as this muscle derives its chief nerve supply from the musculo-cutaneous nerve.

If there is troublesome oozing from cicatricial tissue, the wound will require to be drained.

Tension on the sutured nerve is best avoided by maintaining the forearm in the flexed and pronated position.

Next, let us suppose we have to deal with an extensive lesion of the nerve *as it occupies he musculo-spiral groove.* The usual procedure is to make a long oblique incision across the back of the arm in the line of the nerve, which is then exposed by dividing the outer head of the triceps. The disadvantages of this method are: (1) the division of the

muscle, and (2) the inability to bring the divided ends of the nerve into apposition when, as so often happens, 3 in. or so have to be resected. It is in such cases that the transposition method proves so valuable. Suppose, for example, that the musculo-spiral is extensively involved at the *upper end* of the groove. The nerve is first exposed on the inner side of the arm in its upper half between the lesion and the axilla, care being taken not to injure those of its motor branches which have already been referred to as coming off opposite the insertion of the latissimus dorsi. The lesion itself is then followed into the upper part of the musculo-spiral groove. The steps of this operation have been already fully described (see p. 179).

The nerve is now exposed at the junction of the middle and lowest thirds of the arm through a separate incision in the manner described above, and the lesion is then followed upwards into the lower part of the groove. (Figs. 95, 96, and 97.) The two dissections can be made to meet without actually joining the skin incisions and, what is more important, without cutting across the outer head of the triceps. The whole extent of the lesion having been freed from its adhesions to the triceps and humerus, the nerve is divided above and below the destroyed portion. An oblique tunnel is then made in an upward direction beneath the brachialis anticus muscle, between it and the front of the humerus, and forceps are passed along it in the opposite direction, so as to grasp the lower stump of the nerve and pull it upwards through the tunnel until it emerges above the upper end of the groove where it is sutured to the upper stump. If, on the other hand, the lesion is situated at the lower end of the musculo-spiral groove, the same dissections are made, the only difference being that the upper stump is pulled from above downwards through the tunnel and united to the lower stump at the lower end of the groove. It will be observed that the motor branches of the musculo-spiral come off for the most part above and below the resected portion of the nerve ; it is only the dorsal cutaneous branches, an unimportant branch to the brachialis anticus, and possibly, the branch to the supinator longus that have to be sacrificed. In applying the dressing, the elbow should be maintained in the position of full flexion with the forearm pronated.

The war has taught us that resection of the musculo-spiral nerve followed by end-to-end sutures gives results superior to those which follow resection and suture of any other nerve, the explanation no doubt being that the musculo-spiral is almost entirely a motor nerve, and that we are accustomed to measure the results of nerve-suture operations according to the degree of restoration of the motor, rather than of the sensory and trophic, functions. Seeing then that the results of suture of the musculo-spiral are so good, it is the duty of the operator to take advantage of any step in the technique of the operation which will enable

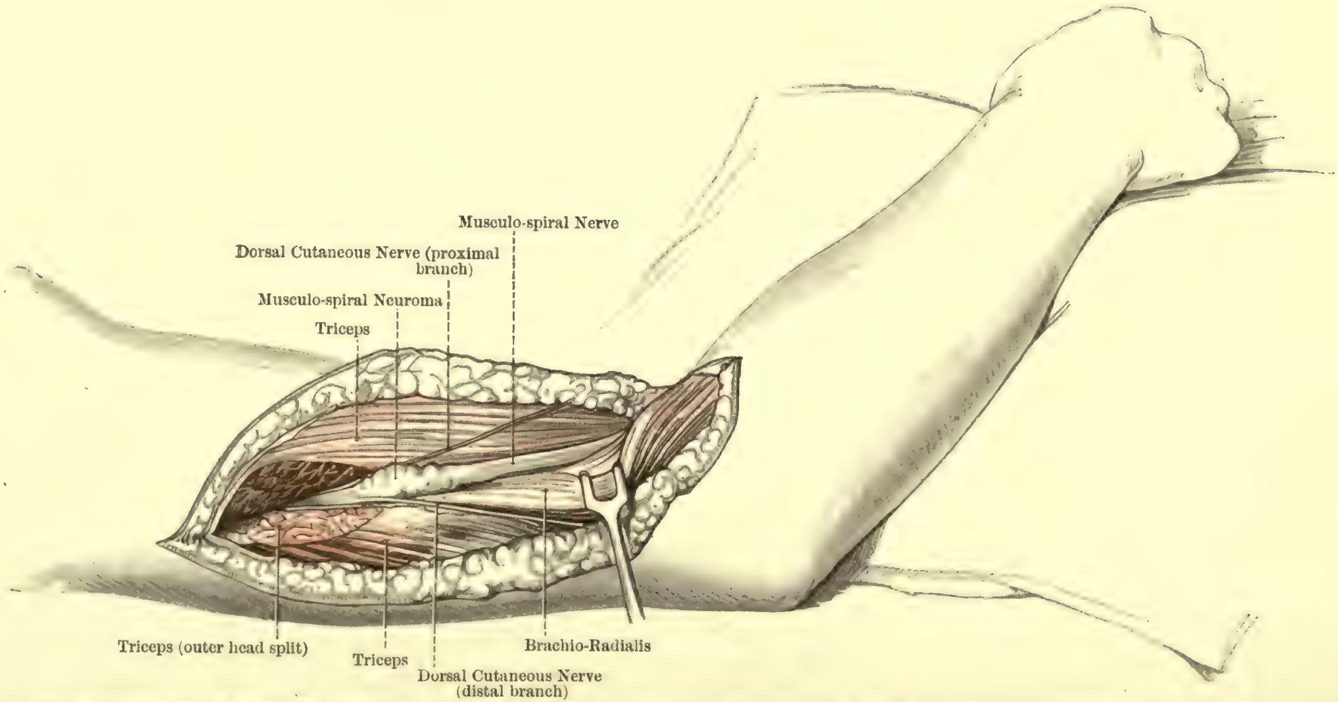


FIG. 96.—Second stage of operation shown in Fig. 94. Lesion of musculo-spiral exposed just distal to where the nerve pierces the external intermuscular septum. Supinator longus muscle retracted backwards.

the divided ends to be brought into apposition without tension after the resection of as long a segment of the nerve as possible. Captain M. S. Danforth, one of my senior assistants at the Orthopædic Centre of the Edinburgh War Hospital, found that by this method of transposition of the nerve from the back to the front of the humerus, he was able to gain an inch; that is to say, he was able to bring into apposition stumps which would have remained an inch apart had he not transposed the nerve from the back to the front of the humerus.

The writer has himself carried out Captain Danforth's method and

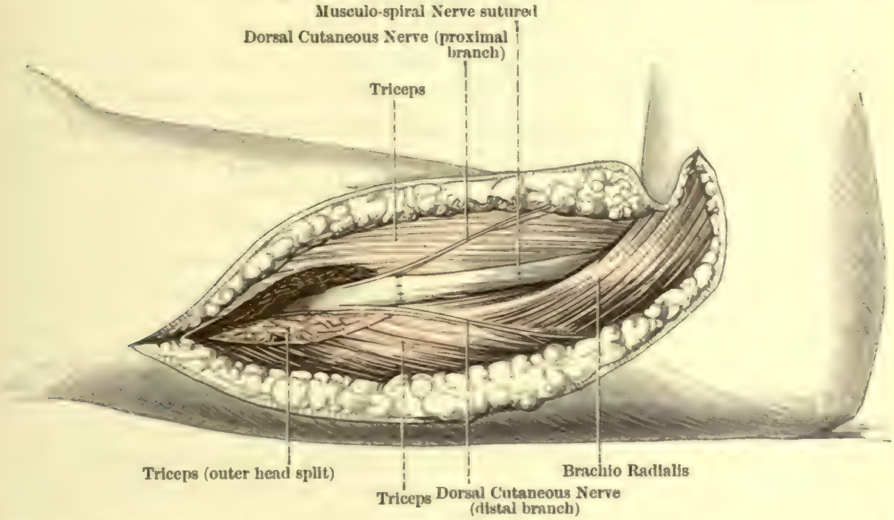


FIG. 97.—Third stage of operation shown in Figs. 94 and 95. Neuroma resected and stumps sutured. Forearm flexed and pronated to relax the nerve.

can strongly recommend it whenever the operator finds difficulty in bringing the ends together after an extensive resection of the nerve in or near the musculo-spiral groove. The gain is due only partly to the fact that by transposing the nerve to the front of the humerus it is made to take a straighter and more direct course; it is due still more to the fact that, when the nerve is brought entirely in front of the humerus, it is capable of much greater relaxation when the elbow is flexed than would be the case if it were left in its natural position behind the humerus.

With regard to the position of the limb after operation, the arm is adducted and the elbow flexed in the manner already described on p. 175.

A special splint is required to maintain the wrist and hand in the proper position, namely, with the wrist dorsiflexed to an angle of 45° and the metacarpo-phalangeal and interphalangeal joints in a position a little short of free extension. The thumb should be kept extended in the position it takes up when grasping a tumbler.

If there is every reason to believe that the lesion of the musculo-spiral is so extensive that even by transposing it the divided ends cannot be brought together, or if an exploratory incision shows this to be the case, the drop-wrist can be dealt with most satisfactorily by tendon transplantation. Indeed, it is safe to say that, of all the operations which the war has added to the orthopædic list, none have given more gratifying results than the operation of tendon transplantation in cases of musculo-spiral paralysis in which nerve suture is out of the question.

Dorsiflexion of the wrist is obtained by transplanting the pronator teres into the extensor carpi radialis longior and brevior muscles, while extension of all three joints of the thumb is got by transplanting the palmaris longus into the extensor secundi internodii pollicis and the flexor carpi radialis into the extensor primi internodii pollicis and the abductor pollicis longus. When the palmaris longus is absent, half the tendon of the flexor carpi radialis is substituted for it. Extension of the fingers at the metacarpo-phalangeal joints is secured by transplanting the tendinous portion of the flexor carpi ulnaris into the tendons of the extensor communis digitorum and the extensor indicis and extensor minimi digiti muscles. Each tendon is buttonholed, and, after 'threading' the aperture with the ulnaris tendon, the latter is stitched to each of the extensor tendons by a linen thread suture. Lastly, the fleshy half of the distal portion of the flexor carpi ulnaris is sutured to the extensor carpi ulnaris, so as to prevent radial deviation of the hand during dorsiflexion.

The splinting of the wrist and hand and the after-treatment are very essential, and for the necessary details the reader is referred to the section dealing with tendon transplantations (p. 291).

POSTERIOR INTEROSSEOUS NERVE

Lesions of the posterior interosseous nerve and its branches are seldom amenable to direct surgical treatment, because no sooner has the nerve trunk traversed the supinator brevis muscle than it proceeds to break up into a leash of small branches, some of which enter the deep surface of the extensor digitorum communis muscle, while others descend beneath that muscle to supply the extensor carpi ulnaris and the special extensors of the thumb and index finger.

Operations on the back of the forearm are generally performed for the purpose of removing scar tissue and repairing muscles and tendons, or for tendon transplantations, and in these operations the surgeon is concerned more with avoiding than with attacking the posterior interosseous nerve and its branches. It occasionally happens, however, that the posterior interosseous nerve is injured between its origin from the musculo-spiral and its exit from the substance of the supinator brevis muscle. The best access to the nerve is got by freely mobilizing the two

radial extensors of the wrist. This is done by splitting the intermuscular septum first between these muscles and the supinator longus and then between them and the extensor digitorum communis ; then, by separating the extensor carpi radialis longior from the supinator longus right up to the external supracondylar region of the humerus and retracting the latter muscle well forwards, the bifurcation of the musculo-spiral nerve is reached. If the radial extensors of the wrist be now well freed down the forearm and retracted to the radial side, while the extensor digitorum communis is retracted towards the ulnar side of the forearm, a space is opened up at the bottom of which the oblique fibres of the supinator brevis muscle are exposed. By dividing the fibres of this muscle in the line of the nerve, the latter is fully exposed, and if only a limited portion of it has been destroyed an end-to-end suture can be effected by fully flexing as well as fully pronating the forearm. If the stumps cannot be approximated, a portion of the radial nerve should be used to bridge the interval.

In splinting the limb at the close of the operation flexion and pronation of the forearm may be maintained by means of a Jones's double-gutter elbow splint, the wrist and fingers being dorsiflexed on a long cock-up splint.

ULNAR NERVE

In Lower Two-thirds of Forearm. Here the ulnar nerve gives off no motor branches, and of the two sensory branches which come into the field of operation, one, namely the palmar cutaneous branch, may be disregarded, while the other, the dorsal digital branch is more important. It should be preserved if possible, because blisters and ulcers are peculiarly liable to occur as a result of anæsthesia of the skin over the dorsal aspect of the little finger.

In dealing, however, with extensive lesions of the ulnar, proximal to the dorsal digital branch, the latter may prevent the lower stump being pulled far enough upwards to meet the upper stump. When this is the case, the operator should not hesitate to divide it, if by so doing the stumps can be approximated, it being taken for granted, of course, that the branch has previously been extensively freed in both directions.

To expose the ulnar in the lower two-thirds of the forearm, an incision is made along the lower two-thirds of a line extending from the posterior aspect of the internal epicondyle to the outer border of the pisiform bone. The superficial veins having been secured, the deep fascia is split in the line of incision. The nerve should be exposed in the first instance in the lower third of the forearm. The well-defined edge of the tendinous portion of the flexor carpi ulnaris muscle is the best guide to the nerve. (Fig. 98.) After this tendon has been freed and retracted well inwards and some-

what backwards, the nerve will be seen to lie immediately dorsal, rather than internal, to the ulnar artery and its venæ comites. Note that the nerve is in close contact with these vessels and that all these structures are covered by a thin layer of fascia, which binds them down to the inner border of the flexor digitorum profundus muscle. The dorsal digital branch above referred to arises from the ulnar about the junction of the middle and lower third of the forearm. If necessary, it may be freed from within the sheath of the ulnar to a considerably higher level. To follow the nerve through the middle third of the forearm, the intermuscular septum between the flexor carpi ulnaris and the flexor sublimis digitorum must be opened up and the two muscles well retracted,

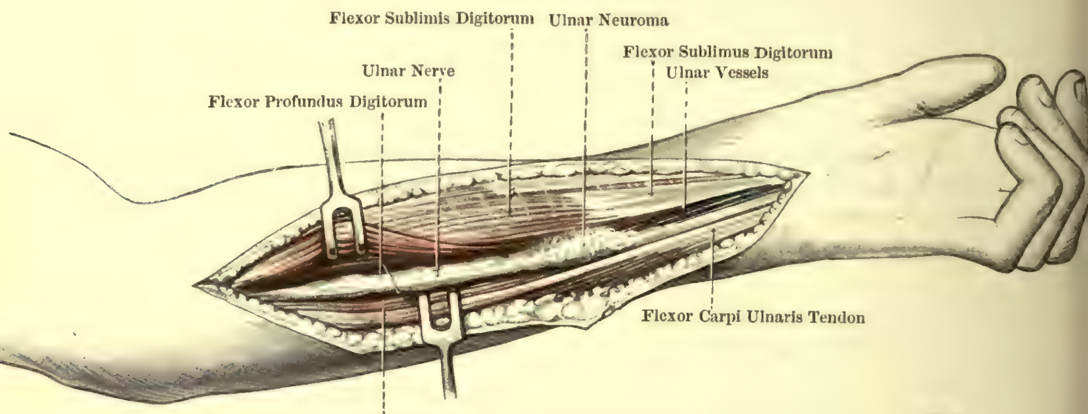


FIG. 98.—First stage of operation for the resection of an extensive lesion of the ulnar nerve in the forearm. The nerve has been exposed by opening up the septum between the flexor carpi ulnaris and flexor digitorum sublimis muscles.

especially the former. To strike the septum, all we have to do is to follow upwards the tendon of the flexor carpi ulnaris. The ulnar nerve is now seen at the floor of the wound which is formed by the flexor profundus muscle. The ulnar artery and its venæ comites here lie a little lateral to the nerve. (Fig. 98.)

Owing to the close relation of the ulnar nerve to the vessels, it is often firmly adherent to them opposite the lesion, and not infrequently they have been partially destroyed and their place taken by dense scar tissue. A portion of the flexor carpi ulnaris and of the inner part of the flexor digitorum sublimis and profundus with their tendons may have suffered the same fate, in which case these structures will have to be repaired after all the scar tissue has been removed. Excellent results are obtained by transplanting the distal stumps of the innermost tendons of the flexor profundus into the two outer tendons. Or the tendon of the palmaris

longus, if present and uninjured, may be divided and transplanted into the distal stump of the severed tendon ; or half the tendon of the flexor carpi radialis muscle may be made use of for a similar purpose.

Let us now suppose that the lesion of the ulnar nerve in the lower two-thirds of the forearm is so extensive that, after resecting the injured portion, the stumps cannot be approximated. In dealing with such a condition, our first choice lies between either approximating the bulbs as nearly as possible by means of traction sutures or shortening the course of the nerve by transposing it to the front of the elbow. By the latter procedure, not only is the nerve made to take a straight and therefore a shorter course, but by placing it in front of the limb we are able to take full advantage of flexion of the elbow, which serves to shorten its course still more. This is a procedure which the writer has invariably chosen, in the first place because the nerve can generally be transposed without sacrificing its motor branches to the flexor carpi ulnaris and the inner half of the flexor profundus muscles, and, secondly, because we have now had a sufficient number of recoveries after adopting this method to know that the extensive freeing of the nerve, combined with its transposition, does not interfere with its regeneration. In the rare cases where, in order to get the stumps together, it is necessary to make the transplantation still more complete, the branches above mentioned have to be divided (Fig. 100) ; the sacrifice is more than justified, because we now know that in the long run the patient will generally regain sensation and the use of the ulnar intrinsic muscles of the hand, which will more than compensate him for the paralysis of the flexor carpi ulnaris and of the profundus tendons to the ring and little fingers. Moreover, this paralysis can to a large extent be circumvented by dividing the two inner tendons of the flexor profundus muscle and suturing them to the two outer tendons, which receive their supply from the median nerve.

If the lesion of the ulnar nerve should happen to be in the upper part of the forearm, its motor branches may have already been destroyed, in which case there need be no hesitation about doing a complete transposition. Should it happen that the patient's elbow is also ankylosed at an obtuse angle, it may not be possible to approximate the stumps in consequence of the inability to flex the elbow. Unfortunately, it is in just such a case that little can be hoped for by applying traction sutures to the bulbs, as the only means by which the nerve can be lengthened is by gradually extending and then dorsiflexing the wrist. It is, therefore, in a case of this kind that we may have to resort to nerve-grafting, to a flap operation, or to shortening of the humerus. If the case were a suitable one it might be worth while considering the advisability of doing an arthroplasty of the elbow before attacking the nerve.

In describing the operation of transposition and suture of the ulnar

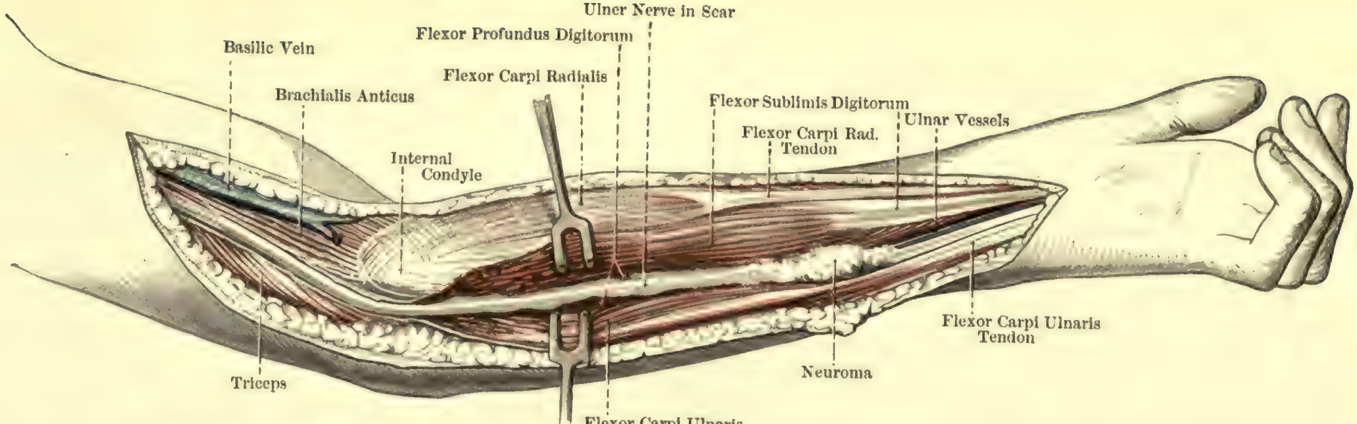


FIG. 99.—Second stage of operation shown in Fig. 97. Ulnar nerve dissected free up to the middle of the arm.

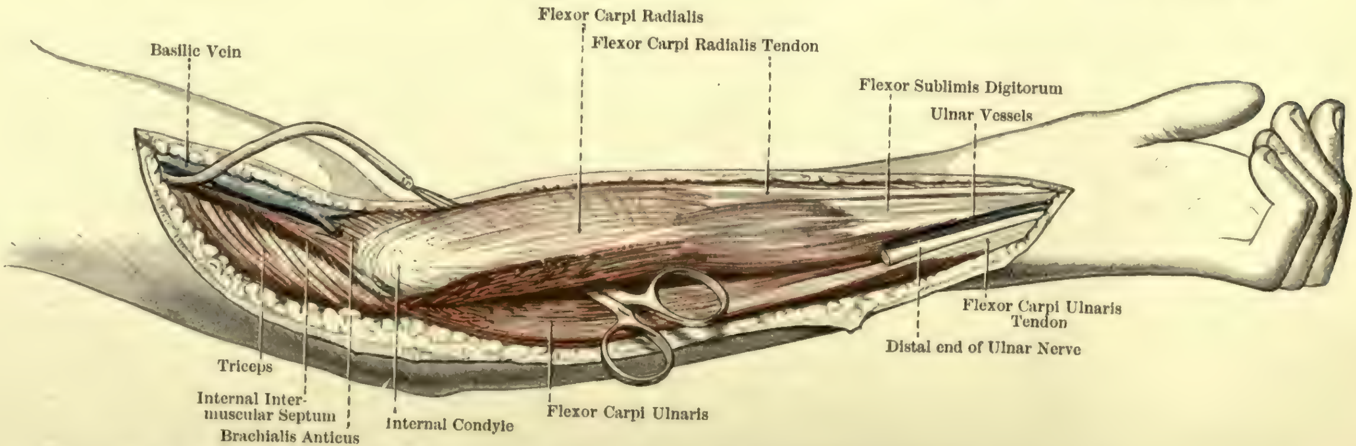


FIG. 100.—Third stage of operation shown in Figs. 97 and 98. The injured portion of the nerve has been resected and the proximal stump has been seized with forceps and is about to be transposed to the front of the elbow by pulling it through a tunnel made between the superficial and deep flexors. By flexing the elbow and the wrist an end-to-end suture can be carried out. In this case the branches of the ulnar to the flexor carpi ulnaris and the inner half of the flexor digitorum sublimis had to be sacrificed.

nerve we cannot do better than take as an example a case in which the nerve has been extensively injured in the lower two-thirds of the forearm, and in which it has been necessary to resect more than 3 in. The operation will be a continuation of that which has just been described. The incision, which has been confined to the lower two-thirds of the forearm, is prolonged upwards, a little in front of the internal condyle, and is continued up the inner aspect of the arm a little behind the medial border of the biceps and coraco-brachialis muscles. Both edges of the wound are undermined in the region of the elbow. The anterior flap is reflected forwards so as to expose the outer border of the pronator teres muscle, and in doing this the median basilic vein is secured by two forceps and divided between them. The internal cutaneous nerve may generally be preserved. The posterior flap is reflected back beyond the internal condyle, and, higher up, behind the internal intermuscular septum. The ulnar nerve is now exposed, as it lies immediately behind the lower part of the septum, where it is sometimes so sunk in the substance of the triceps as to be almost hidden from view. It is in this situation that the inferior profunda artery will be encountered ; here it can generally be freed along with the nerve, but, behind the internal condyle, where it anastomoses with the ulnar recurrent vessels, it will have to be divided, and it must be secured with forceps, as the bleeding is troublesome. The nerve is now freed from the back of the internal epicondyle. Here it is covered by a thick fascia, which is often so closely adherent to the nerve that care must be taken not to injure it. The nerve is next followed into the forearm by splitting the flexor carpi ulnaris muscle in the interval between its humeral and ulnar origins, and the dissection is continued downwards through the substance of the muscle until the upper limit of the previous dissection is reached. It is at this stage of the operation that the branches which are given off by the ulnar nerve to the forearm muscles are carefully exposed and freed, as far as possible, in both directions. Each head of the flexor carpi ulnaris receives a separate branch, each of which arises from the corresponding aspect of the nerve about an inch below the internal condyle. The inner portion of the flexor digitorum profundus receives two or three branches which arise about an inch lower down. If the gap in the ulnar nerve is a large one, it will be necessary to follow it through the internal intermuscular septum and to free it well up towards the axilla. This is done with the object, firstly, of straightening out the slight but distinct angle which the nerve makes as it enters the septum, and, secondly, so that full advantage may be taken of applying traction to the nerve before it is sutured. In tracing the nerve through the septum care must be taken not to injure the small ulnar collateral branch of the musculo-spiral which courses downwards immediately in front of it to supply the inner head of the triceps.

The proximal segment of the ulnar nerve having been freed from the lower part of the forearm to the upper third of the arm, it is now brought in front of the elbow as far towards its centre as the dissected-out motor branches will admit. The nerve must not be allowed to remain superficial to the internal condylar group of muscles, partly because it would be too much exposed to irritation, so that a painful neuroma would be liable to form, and partly because the maximum relaxation of the nerve would not be obtained if it were left to arch over the convexity of the muscles. These muscles, namely the pronator teres, the flexor carpi radialis, the palmaris longus, and the subjacent fibres of the flexor digi-

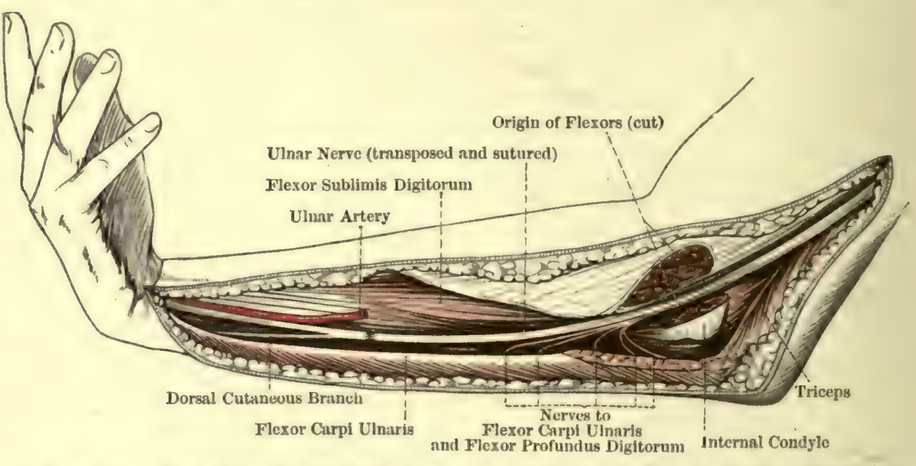


FIG. 101. End-to-end suture of ulnar nerve after resection of a lesion involving it in the middle third of the forearm. The nerve has been freed from the wrist to the junction of the lower and middle thirds of the arm. The branches have been freed so as to allow of the transposition of the trunk of the nerve to the front of the internal condyle, where it has been sunk into a trough made in the flexor muscles, which are then sutured over the nerve. The elbow and wrist maintained flexed to prevent tension on the sutures.

torum sublimis are divided opposite and in the direction of the transposed nerve, and the latter is then sunk into the muscular trough, the floor of which is formed by the upper fibres of the flexor digitorum profundus muscle. The divided muscles are then sutured over the nerve. (Fig. 101.)

It will be observed that by adducting the upper arm and fully flexing the elbow and ulnar-flexing the wrist, along with traction on the two segments of the nerve (before the bulbs have been removed), the freshened stumps may be approximate even after 4 or 5 in. of the nerve has been resected. Reference to Fig. 102 will show that the proximal segment may be pulled downwards to such an extent that the motor branches of the ulnar may be made to take a recurrent direction as they pass from their origins to enter the muscles.

If these motor branches have already been destroyed, or if it is necessary to sacrifice them in order that the ulnar nerve may be made to take a straighter course, the muscles above-mentioned need not be divided. Instead of this the proximal segment of the nerve is pulled from above downwards through the tunnel made beneath the muscles, as shown in Fig. 100. The tunnel is made partly with a blunt instrument, such as a Kocher's dissector, and is then widened, either by forceps or by the index finger. In making the tunnel, care must be taken to see that it runs beneath and not through the fibres of the flexor digitorum

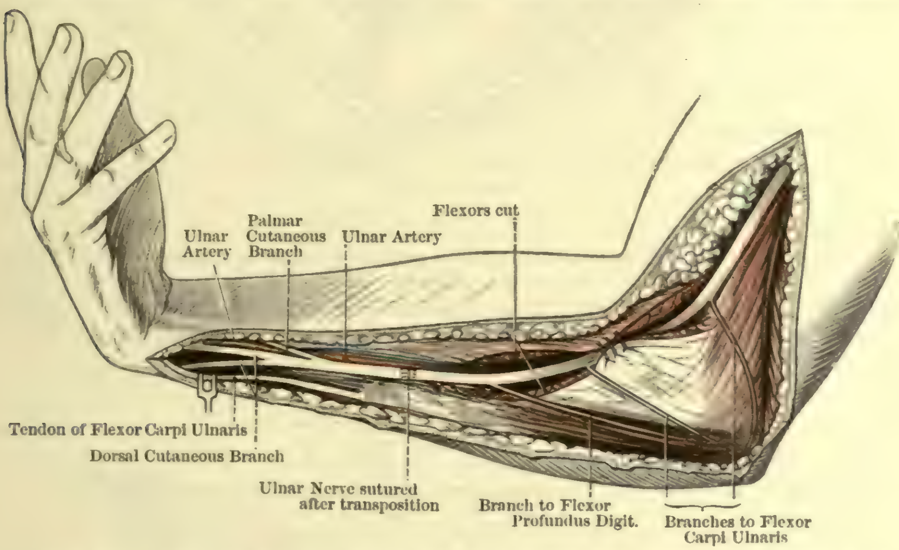


FIG. 102.—Operation similar to that shown in Fig. 100 except that more of the ulnar nerve (4 in.) had to be resected. Note the recurrent course taken by the motor branches after the proximal stump has been pulled down and sutured to the distal stump. Flexor carpi ulnaris muscle partly replaced by scar tissue. Elbow and wrist-joints flexed to take tension off the nerve. The patient is recovering epicritic sensation and the function of the intrinsic muscles of the hand. The stretched motor branches to the forearm muscles have continued to functionate well. The elbow- and wrist-joints could be fully extended eight months after the operation.

sublimis, and the operator must take care also not to injure the ulnar artery.

After the nerve has been pulled downwards through the tunnel, it is important to see that it is neither kinked nor tacked down in any way by the intermuscular septum. It is a good plan to remove that portion of the septum which is crossed by the nerve, so that the latter may not rest upon its sharp edges.

The upper-arm portion of the wound must be closed before the nerve is sutured, because, while the latter is being done, the limb must

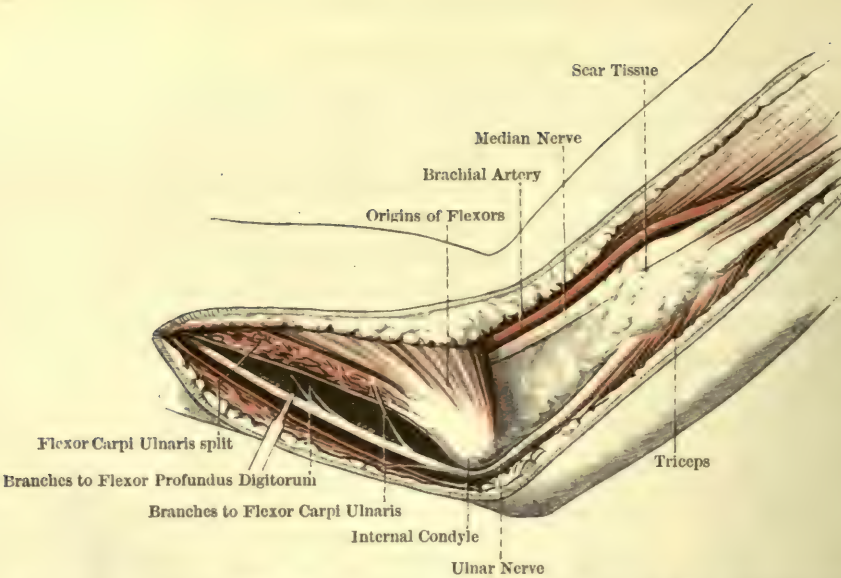


FIG. 103.—First stage of operation for a lesion of the median and ulnar nerves in the lower third of the arm. Motor branches of ulnar freed to allow of its transposition to the front of the elbow. This procedure was necessary, otherwise the elbow could not have been flexed to obtain an end-to-end suture of the median nerve.

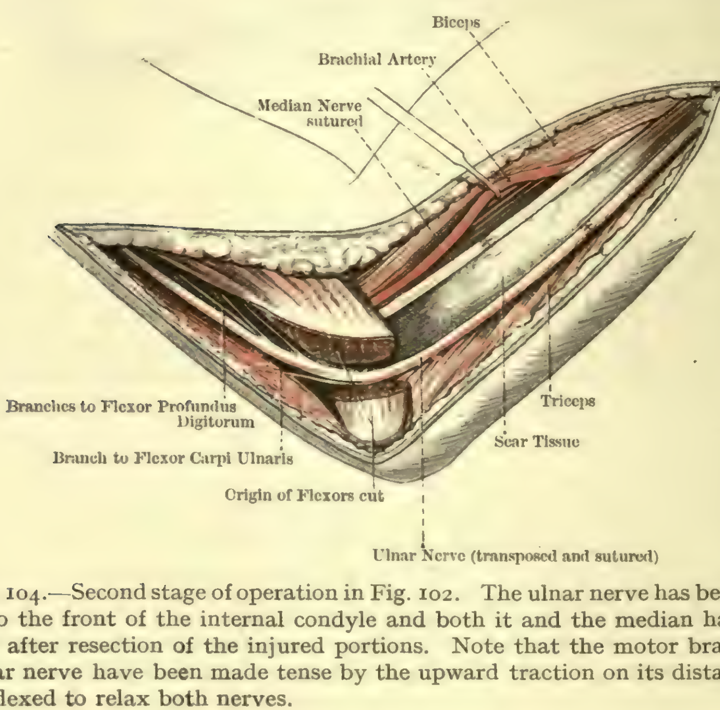


FIG. 104.—Second stage of operation in Fig. 102. The ulnar nerve has been transposed to the front of the internal condyle and both it and the median have been sutured after resection of the injured portions. Note that the motor branches of the ulnar nerve have been made tense by the upward traction on its distal stump. Elbow flexed to relax both nerves.

be adducted and maintained in this position during the remainder of the operation and for two or three weeks subsequent to it. It is an advantage, therefore, to use catgut in suturing this portion of the wound. The limb should, of course, be bandaged to the chest with the forearm fully flexed and the wrist kept in the position of ulnar flexion. The stage of right-angled abduction of the arm should not be reached until six or eight weeks from the date of operation.

When transposition is necessary for a lesion of the ulnar nerve in the upper arm, it will be found that the gain derived by dissecting up the motor branches is much less than in a forearm lesion, as in this case the operator is not approximating the points of their origin and entry into the muscles they supply. Again, if sacrifice of the forearm branches is necessary in the case of an upper-arm lesion, it will be the distal portion of the nerve which passes through the tunnel beneath the flexor muscles ; the line of suture in this case lies above the tunnel and not below it, as in a forearm lesion. (Figs. 103 and 104.)

When the line of suture happens to fall within the tunnel beneath the flexor bellies the latter must be divided in the line of the displaced nerve, which is then dropped into the trough, the muscles being then resutured over it.

In splinting the limb after the operation, adduction of the upper arm, flexion of the elbow and palmar flexion of the wrist towards the ulnar side are, when necessary, obtained respectively by means of a body bandage to fix the arm to the side, a Jones's double-gutter elbow splint for the elbow and a small single gutter splint bent to the requisite angle opposite the wrist. To maintain the physiological position of the hand and to prevent contractures, Captain Danforth, U.S. Army, has devised a small hand splint of papier mâché, which is applied to the palm and fingers and retained in position by straps and buckles ; the splint is made from a plaster model of the hand held in the physiological position. Should the condition of ulnar griffe be already established or imperfectly cured, a suitable form of finger-traction splint will have to be used.

MEDIAN NERVE

In Lower Two-thirds of Forearm. In dealing with the median in the lower two-thirds of the forearm, it should be remembered that immediately above the wrist the nerve is relatively superficial, whereas when traced upwards it lies deeply under the radial head of the flexor sublimis digitorum. The incision to expose the nerve should be made in the line of the flexor carpi radialis tendon. In the lower third of the forearm, the nerve is best reached by retracting the tendon outwards, but in the middle third the best access is obtained by inward retraction of the muscle ; at this level, exposure is completed by dividing the radial head of

the flexor sublimis digitorum near its radial attachment. In doing this the proximity of the radial vessels and nerve should be kept in mind. An important point to remember, too, is that the nerve clings to the deep aspect of the flexor sublimis digitorum and is liable to be retracted along with that muscle, in which case it would be sought for in vain on the flexor profundus digitorum muscle, which forms the floor of the wound. The small arteria mediana serves as an additional guide to the nerve. (Fig. 105.)

The median, when exposed by the above method, is easily traced down to the wrist. Just above the wrist it is overlapped by the flexor carpi radialis and palmaris tendons, but when these are destroyed only fascia separates it from the skin. In cases where there is much scar tissue the nerve may be drawn forwards from its bed and become closely adherent to the skin; in these circumstances the scar may be acutely painful, and it is easy to injure the nerve when making the skin incision. The palmar branch of the median pierces the deep fascia a little above the annular ligament, and it also is not infrequently involved in the scar. At the end of the operation, it is important to see that the median nerve does not lie immediately under the skin, otherwise a painful neuroma may result. This can generally be avoided by roofing over the nerve by the lower fleshy part of the sublimis, which can be stitched to the deep fascia in the neighbourhood of the tendon of the flexor carpi ulnaris.

In exceptional cases, owing to the position of the scar which has resulted from the original injury, or it may be from a previous operation, it may be necessary to expose the median in the lower half of the forearm by an incision placed nearer the medial border of the limb and then to free, retract outwards, and evert the medial border of the flexor sublimis digitorum until the nerve is reached between this muscle and the flexor profundus digitorum.

In suturing the median in the lower two-thirds of the forearm the chief relaxation is obtained by flexion of the wrist; comparatively little is obtained by flexion of the elbow, owing to the nerve being anchored by the numerous motor branches which come off in the upper third of the forearm.

The anchoring of the proximal stump of the divided median nerve by the branches which it gives off in the upper part of the forearm can, to a large extent, be overcome by dissecting them well into the muscles they supply and by freeing them up along the parent nerve to a point well above the elbow. This manœuvre is less successful in relaxing the distal portion when the lesion is in the upper arm, but even in these cases it is of some help. (Fig. 107.)

Gaps to the extent of 4 or 5 in. can be dealt with by the method described. Approximately 1½ in. are gained by free dissection, 1 in. by

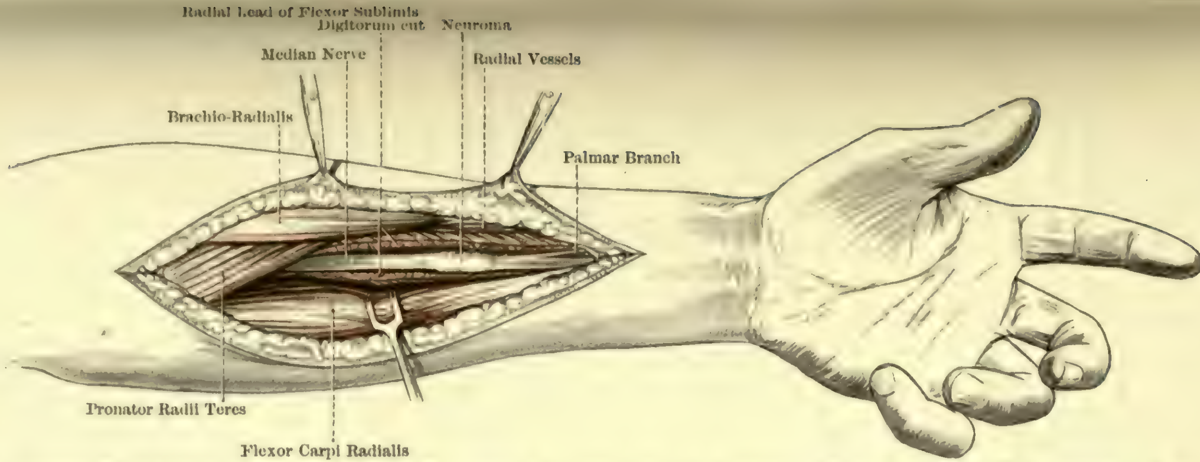


FIG. 105.—Operation for neuroma of median nerve in lower half of forearm. Flexor carpi radialis retracted inwards and radial head of flexor digitorum sublimis divided along the line of the nerve.

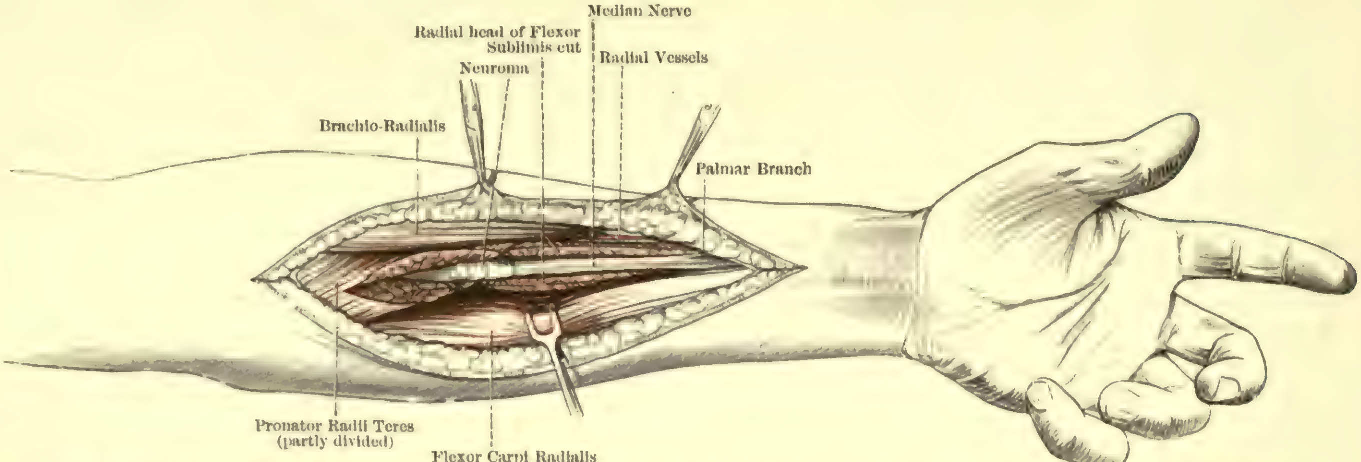


FIG. 106.—Median nerve exposed in upper third of forearm by dividing pronator radii teres—a method for use when the scar tissue has involved that muscle where it crosses the nerve.

efficient freeing of the branches, and 1½ in. by flexion of the joints. In the case of a more extensive gap, the wisest plan is to suture the untrimmed stumps of the nerve at the first operation, and after the nerve has been slowly stretched (as above detailed in chapter on General Considerations, p. 156), to re-expose the nerve at a second operation when a satisfactory end-to-end suture can generally be accomplished. This two-stage slow-stretching method will in most cases obviate the necessity of resorting to nerve-grafting, &c. The procedure is more likely to be needed when the elbow is ankylosed at an obtuse angle or even at an angle of 90°. The question of doing an arthroplasty of the elbow may have to be considered in such a case.

Before leaving the median nerve, reference must be made to the frequency with which it is found to be firmly adherent by dense scar tissue to the long flexor tendons, both sublimis and profundus ; and not infrequently the tendons themselves are firmly adherent to one another, and one or more of them may have been completely destroyed. In these cases the freeing and suturing of the median nerve forms only a part of the operation ; equally important is the freeing and repair of the tendons. All trace of scar tissue must be carefully dissected away. The tendons must be freed, and the distal stumps of those which have been completely severed must be sutured either to an adjacent intact tendon, sublimis to sublimis and profundus to profundus ; or, what is sometimes preferable, the palmaris longus and flexor carpi radialis, whichever is uninjured, or both, may be severed close to the annular ligament and sutured to the distal stump, or stumps, of the divided flexor tendons. When several of the long flexor tendons have been destroyed both methods will have to be employed.

At the Elbow and Upper Third of Forearm. A single dissection will suffice to illustrate the operative technique which is called for in dealing with lesions of the median nerve in this locality. The incision is made along the inner border of the biceps in the lower third of the arm, and crosses the antecubital fossa a little internal to the tendon of the biceps, passing thereafter down the middle of the upper third or more of the fore-arm. It is best to find the nerve above the elbow and trace it downwards, injury to the branches being thus more easily avoided. It is usually necessary to divide and double ligature the median basilic vein just above the bend of the elbow, the internal cutaneous nerve being freed and retracted inwards. The deep fascia having been incised along the inner border of the biceps, the nerve will be found lying a little internal to the artery.

The next step is to define the outer border of the pronator radii teres, care being taken not to injure its upper branch of supply, which comes off the inner border of the median at the level of the internal condyle

and runs parallel to the main trunk for a distance of about 1 in. The belly of the pronator teres must now be powerfully retracted in a downward and inward direction so that the median can be followed into the upper part of the forearm. As it passes between the two heads of the pronator muscle it gives off a leash of branches, the second branch to the pronator, chiefly for the supply of its deep head, arising from the radial side of the nerve. All the other branches come off from a single bundle which can be traced up the mesial side of the nerve to about 1 in. above the bend of the elbow. From the front of this leash, branches enter the deep aspect of the flexor carpi radialis, the palmaris longus, and the flexor sublimis digitorum muscles ; from its posterior aspect passes the anterior interosseous nerve which descends behind the tendinous arch of the sublimis, to supply the radial half of the flexor profundus digitorum, the flexor pollicis longus, and pronator quadratus. It is while tracing the median beneath the superficial head of the pronator radii teres muscle that the difficulties of the operation are encountered ; these difficulties are the result of the close relation of the nerve to the ulnar artery, its venæ comites, and to the profunda vein. The motor branches are best avoided by dissecting from above downwards along the outer aspect of the nerve.

To trace the nerve distal to the pronator, the incision is continued distally along the radial border of the flexor carpi radialis, which must be freed completely, care being taken not to wound the radial artery or its venæ comites where they cross the radial attachment of the pronator to disappear beneath the fleshy belly of supinator longus. The dissection is deepened by splitting the intermuscular septum between the pronator teres and flexor carpi radialis ; when this has been done, the two muscles are well retracted so as to enable the operator to expose and divide the tendinous arch which connects the radial with the condylo-ulnar portion of the flexor sublimis digitorum. (Fig. 107.) With regard to the nerve supply of the flexor sublimis digitorum, its condylo-ulnar head is supplied high up by a nerve arising alone or in connexion with that to the superficial muscles. A separate branch enters the radial head, and a third branch is given off still lower for the supply of the belly to the index finger (Quain).

Owing to the depth of the median in this situation, to the number of branches given off and to its close relation to the ulnar artery, to its venæ comites and profunda vein, it is essential to obtain a good exposure of the parts. If, therefore, free retraction of the pronator radii teres fails to give sufficient exposure, the operator should not hesitate to cut the muscle across. Fortunately its main nerve of supply, which comes off from the median at the level of the internal epicondyle, enters the upper part of the muscle. This nerve should be sought for and isolated when the supero-lateral border of the muscle is being freed.

The greatest possible care should be taken to avoid unnecessary

injury to the motor branches, especially those which go to supply the flexors of the thumb and fingers. If the lesion *has already destroyed the median where these branches are given off*, there should be no hesitation about continuing the dissection to any extent in both directions, provided the nerve stumps can be brought into contact without undue tension after the injured segment has been resected. The reason for doing everything possible to obtain an end-to-end suture, even although there is no

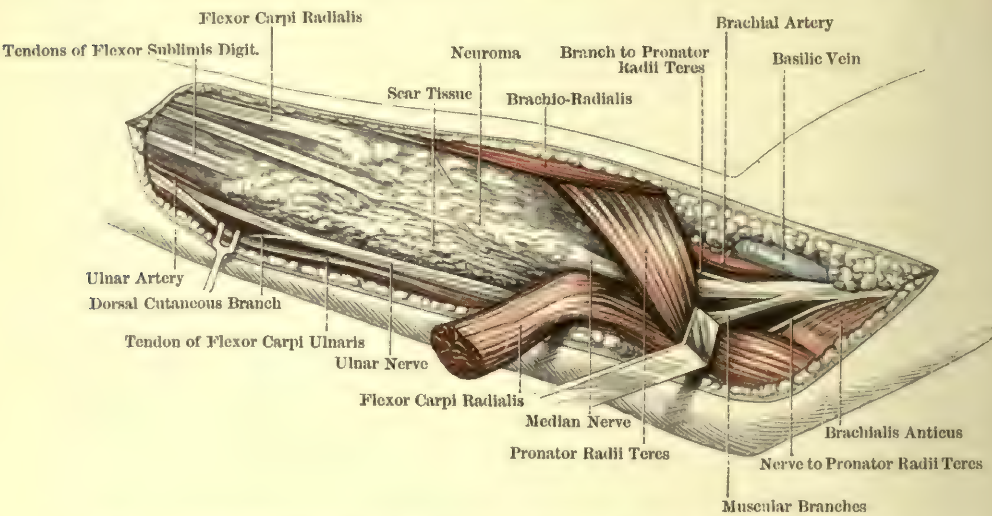


FIG. 107.—Extensive lesion of median nerve in middle of forearm. End-to-end suture was possible after freeing the branches up from the nerve and pulling its proximal end down till they became recurrent, and then flexing the wrist and elbow completely. Flexor carpi radialis sutured ; tendons freed. After six months the joints extended freely, and patient was recovering power in the thenar muscles and median sensation and had the use of all the flexors.

hope of the patient recovering from his motor paralysis, is that there is every probability that sensation will be restored and that the trophic symptoms will disappear. Moreover, should severe neuralgia exist, this may also disappear, or at any rate be greatly relieved, by the resection. The paralysis can be subsequently dealt with by tendon transplantation.

The importance of restoring sensibility is well illustrated in injuries to the median in the lower half of the forearm. Here, although the nerve supply of the long flexors is not interfered with, the patient experiences great impairment of the motor function of the thumb, not merely as the result of the paralysis of the intrinsic muscles of the hand supplied by the median but also from the loss of sensation in the digits. If, for example, he be asked to button his coat, it will be observed that the difficulty arises from his inability to feel when he has got a proper grasp of the button.

Hence the importance of making every attempt to obtain an end-to-end suture of the median nerve in spite of the fact that its motor branches may have already been destroyed. By extending the dissection from the wrist well up into the axilla the ends can be approximated after as much as 6 in. of the nerve has been destroyed.

After operations on the median nerve, the elbow and wrist are splinted in the same manner as has been described in dealing with the ulnar nerve except that there is no necessity for ulnar flexion at the wrist. With regard to the hand it is important to maintain the integrity of its transverse arches, so as to prevent stretching not only of the transverse ligaments but also of the paralysed thenar muscles. This is best done by using Danforth's splint described on p. 195. If this splint is not available a leather glove may be employed ; this should be provided with a strap and buckle extending transversely across the palm of the hand at the level of the middle of the first metacarpal bone, so that, by tightening the strap, the thumb is maintained in the position of opposition.

Tendon Transplantation for Median Paralysis. In cases where sensation of thumb, index, and middle fingers is preserved or curable, the lost motor function of these digits can be fairly well restored by means of tendon transplantation, &c.

There is no muscle which can be made to act as substitute for the thenar muscles, but it has been found that even when these are completely paralysed, including the adductor pollicis, they will not be much missed if the thumb is arthrodesed at its carpo-metacarpal joint in a position of opposition and abduction, so that the angle between the first and second metacarpals is 60°. Radiographic examination has shown that this angle scarcely varies whether large or small objects are being grasped. It is no disadvantage if this arthrodesis results in a short fibrous, rather than a bony, ankylosis, as this allows slight flexion at the carpo-metacarpal joint. It is a mistake to put the thumb in a position of more than moderate opposition, otherwise the hand is unable to grasp large objects. This arthrodesis operation must precede any transplantation operation to the long flexors, otherwise the tension of the transplanted muscles will be altered by the bone operation and their function upset.

Several possible transplantations are possible to replace the long flexors of the thumb, index, and middle fingers. The one which has been done at the Edinburgh War Hospital with success is as follows :

Into the tendon of the flexor longus pollicis at the wrist is transplanted one-half of the extensor ossis metacarpi pollicis detached as near to its insertion as possible. This ultimately gave very powerful flexion of the terminal phalanx of the thumb.

Should the middle finger, as often occurs, have its profundus supply from the ulnar nerve, the operator may confine his attention to the

flexors of the index finger. The extensor carpi radialis longior is detached from its insertion and brought to the front of the forearm in a subcutaneous tunnel superficial to the supinator longus and then deep to the tendon of the flexor carpi radialis. It is split longitudinally, half being transplanted into the sublimis and half into the profundus tendon of the index finger, just above the anterior annular ligament. The transplantation should be done with more than semi-flexion of the interphalangeal joints, but careful after-treatment is required to prevent permanent shortening.

NERVES OF THE HAND

In extensive lacerated wounds of the hand little or nothing can be done to repair the nerves. Operations designed for this purpose are only undertaken when the nerve lesion is strictly limited, such as may occur as the result of a clean bullet or small shrapnel wound, and especially when a foreign body is present in close contact with the nerve. The operation which is usually done for the relief of pain and tenderness consists generally in the removal of the missile, and if this has already been removed, it consists in the removal of the scar tissue in which the injured nerve is embedded. It is seldom possible to suture the stumps of the nerve. Captain Danforth had a case in which the deep ulnar branch of the nerve had been divided close to its origin. After removing the small area of scar tissue where the nerve had been divided, the stumps could be approximated by full flexion of the wrist.

To expose the ulnar nerve in the palm, an incision is commenced well above the wrist and carried along the flexor carpi ulnaris tendon to the radial border of the pisiform bone, and thence distally into the palm in a direction towards the interval between the ring and little fingers. The nerve is first exposed above the wrist by retracting the ulnaris tendon and in the palm by dividing the palmaris brevis muscle. The deep branch which is given off from the ulnar edge of the nerve opposite the lower border of the pisiform bone is traced to where it pierces the septum between the abductor and flexor brevis minimi digiti muscles. By splitting the septum and retracting these two muscles, the nerve may be followed and freed distally. The branches of supply to the hypothenar muscles generally spring from the deep branch of the ulnar, close to its commencement, so that if they have been injured, the chances are that the ulnar itself has also been involved. When this is the case, an attempt should be made to suture the single stump of the ulnar to its superficial and deep divisions. In Captain Danforth's case the deep division was divided a little distal to where it gives off its branches to the hypothenar muscles. The operation was done for the purpose of restoring the function of the interossei, the two inner lumbricals and the deep thenar muscles.

Operations on the median nerve in the palm usually form part of an operation for the freeing and repair of tendons. When the nerve alone has to be dealt with, it is invariably for the relief of painful conditions resulting from implication of its sensory branches. In the removal of scar tissue which does *not* involve the median or any of its branches care should be taken not to injure the digital branches to the thumb and index finger. If the operator's knowledge of anatomical detail is not equal to the occasion, he should not hesitate to refresh his memory by reference to a text-book of anatomy.

The splinting of the hand after operation has already been referred to (see p. 195).

INJURIES TO THE NERVES OF THE LOWER EXTREMITY

SCIATIC NERVE

From the operator's point of view, lesions of the great sciatic nerve may be divided into (1) those situated in the buttock and upper part of the thigh above the point where the long head of the biceps crosses the sciatic, and (2) those situated below this level.

In the Buttock and Upper Part of the Thigh. In cases of lesions situated in the buttock and upper third of the thigh, the best access is obtained by an incision shaped like a mark of interrogation. The incision is a downward extension of the one employed by Kocher for excising the hip-joint. It extends along the outer two-thirds of a line running from the posterior superior iliac spine to the upper border of the great trochanter, thence downwards a little internal to the posterior border of the trochanter, and then downwards and inwards towards the mid line of the back of the thigh, down which it may be prolonged as far as required.

The thick subcutaneous fat having been divided, the gluteus maximus is split in the direction of its fibres opposite the upper limb of the incision, whilst the lower fibres of the muscle are divided vertically a little internal to their tendinous insertion. (Fig. 108.)

The advantages of this incision are fourfold, namely (1) free exposure; (2) less interference with the nerve supply of the gluteus maximus; (3) less bleeding; (4) skin wound farther away from the ano-genital region.

The inner portion of the muscle is then freed from the deeper structures and reflected inwards with the integuments until the nerve is reached. In doing this, care is taken not to injure the branches of the inferior gluteal nerve when dividing or applying forceps to the branches of the gluteal and sciatic vessels which enter the deep surface of the muscle. The great sciatic nerve is now exposed as it descends in the fat dorsal

to the quadratus femoris and the upper part of the adductor magnus. Forceps are applied to any branches of the superficial divisions of the gluteal artery which have been divided. The lower border of the piriformis muscle is now defined by dividing the subgluteal fascia and separating the subjacent fatty layer with the finger or a Kocher's dissector.

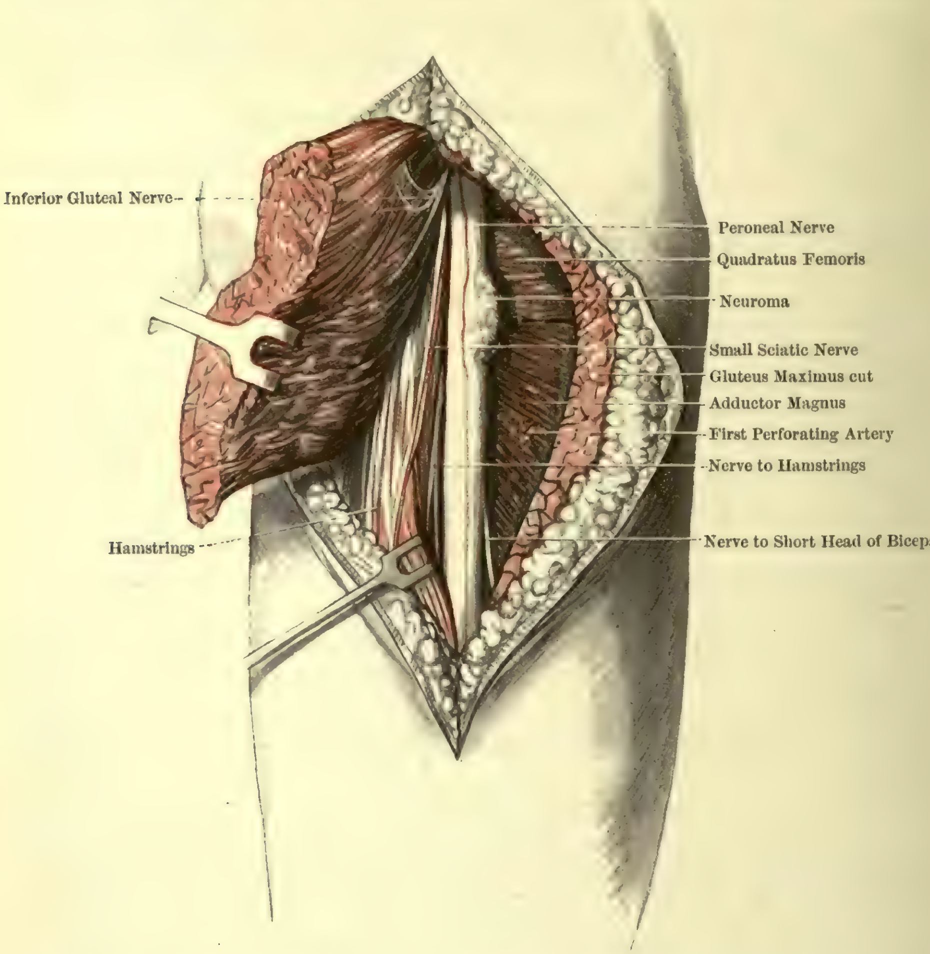


FIG. 108.—Operation for a neuroma involving the peroneal portion of the right sciatic nerve opposite the lower border of the quadratus femoris. Through the upper part of the incision the gluteus maximus has been split; below this the muscle has been divided close to its aponeurosis and reflected inwards.

In freeing and retracting upwards the piriformis muscle, the following structures will be met with immediately dorsal and superficial to the great sciatic nerve, namely the sciatic vessels and their branches, the

inferior gluteal nerve, and the small sciatic nerve. After the vessels have been secured and the deep wound rendered as dry as possible, the above nerves are sought for and traced up to their origin from the dorsal aspect of the lowest part of the sacral plexus. If the small sciatic nerve be not involved in scar tissue, it is freed and displaced inwards. Frequently, however, it is found to be involved in scar tissue along with the great sciatic, in which case there need be no hesitation in sacrificing it, as it is a purely sensory nerve. Care should be taken, however, to preserve as far as possible the inferior gluteal nerve which often arises from the plexus in common with the small sciatic and then breaks up almost at once into a leash of branches which radiate upwards and downwards to enter the deep surface of the gluteus maximus muscle. If the trunk of this nerve is sacrificed, the whole of the gluteus maximus will be paralysed, with the result that the patient will be permanently lame, on account of his inability sufficiently to extend and abduct the thigh.

The great sciatic nerve is now thoroughly exposed and freed from the obturator internus and gemelli muscles, so that the nature and extent of the lesion may be ascertained. The involved portion of the nerve is now completely freed from adjacent scar tissue, the whole of which should be dissected away. This having been done, the nerve is dissected free as far below the lesion as may be necessary.

In order to reach the nerve above the injured segment, the piriformis muscle is thoroughly freed and retracted well upwards, and it may even be necessary to divide the muscle. The upper section may have to be made through the nerve at, or immediately above, the origins of the small sciatic and inferior gluteal nerves, that is to say, through the lowest part of the sacral plexus itself. In following the nerve upwards ventral to the piriformis muscle care should be taken to avoid injuring the pudenal nerve and the nerve to the obturator internus muscle. Sometimes, however, they are involved along with the great sciatic nerve. The nerve to the quadratus femoris muscle, which lies between the great sciatic and the ischium, is still more likely to be involved in following the nerve downward into the thigh. The upper part of the long head of the biceps is thoroughly freed and retracted well inwards. When this has been done, the great sciatic nerve will be found descending on the dorsal surface of the upper part of the adductor magnus muscle, embedded in and surrounded by adipose tissue. (Fig. 109.) Laterally the wound is limited by the deep surface of the fascia lata and the external intermuscular septum which passes from it between the biceps and the vastus externus to gain attachment to the linea aspera of the femur. In working through the fatty layer which surrounds the great sciatic nerve, several small bloodvessels will be encountered superficial to the nerve ; these should be divided between forceps. They are muscular branches derived from

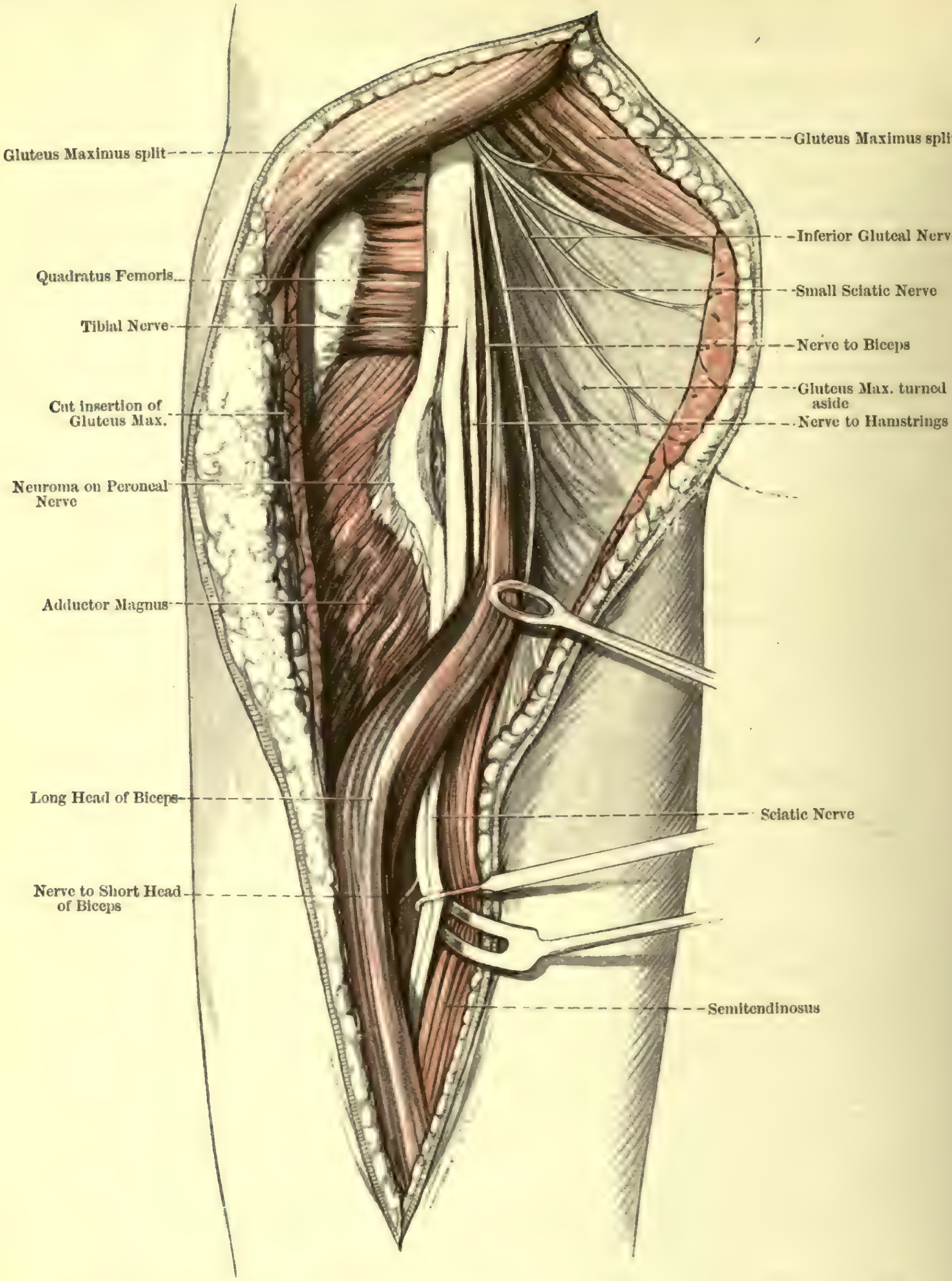


FIG. 109.—Operation for a neuroma involving the peroneal portion of the left sciatic nerve at the level of the gluteal fold. Same method of approach as shown in Fig. 107, except that the dissection has been continued distally into the thigh. The neuroma in the buttock has been exposed by retracting the biceps and semitendinosus muscles inwards; in the thigh the sciatic has been exposed between these two muscles.

the anastomosis between the sciatic, the terminal branch of the internal circumflex, the transverse branch of the external circumflex, and the superior perforating branch of the profunda femoris. More important, however, are the branches of the great sciatic nerve which go to supply the hamstring muscles. These should be sought for and traced to their origin from the great sciatic. They all converge to join its medial border, where they often form a single trunk which can sometimes be dissected free from the injured and bulbous portion of the great sciatic as high up as the quadratus femoris muscle. By paying attention to this point, the nerves of supply to the hamstrings may be preserved instead of being sacrificed accidentally. When freeing the sciatic nerve from the adductor magnus, a sharp look-out should be kept for the branch which comes off from its ventral aspect to enter the upper part of this muscle on its dorsal aspect. Sometimes, especially when the femur has been fractured, the great sciatic is bound down to the adductor magnus by such a mass of dense scar tissue that it is impossible to preserve this branch. Fortunately, however, the adductor magnus is supplied also by the deep division of the obturator nerve.

With regard to the treatment of the operation wound the divided or split gluteus maximus is sutured with 21-day iodine-tannic-gut (Luken's or some other equally reliable brand), and care should be taken not to injure the muscle by tightening the sutures too vigorously. Due attention should be given to hæmostasis in order to do away as far as possible with the introduction of a drainage tube. If, as not infrequently happens, the removal of much scar tissue has been attended with venous oozing which could not be completely arrested, a tube should be introduced. In applying the dressing plenty of wool should be used so that firm pressure may be made during the application of the bandage.

In the Lower Half of the Thigh. While the great sciatic nerve usually bifurcates a little below the middle of the thigh, it may do so anywhere between the sacral plexus and the lower part of the thigh. ' Out of 138 cases recorded by the Collective Investigation Committee the whole of the sciatic nerve emerged from the pelvis below the piriformis muscle in 118 cases ; in 17 cases the nerve left as two trunks, of which one, the peroneal, pierced the piriformis muscle ; while in the remaining three the whole nerve passed through this muscle ' (Quain).

An assistant should have charge of the leg, and his duty should be to see that it is held at whatever angle of flexion the surgeon finds most suitable for the particular step of the operation he happens to be concerned with. A sandbag should be placed under the lower end of the femur so as to extend the thigh a little beyond the straight. This position still further relaxes the nerve and allows also of a more thorough retraction of the hamstring muscles. The thigh should be rotated slightly inwards.

The operation will be best described by taking as a type that which is performed for a lesion of the nerve a little above the middle of the thigh. The incision is carried along the line of the nerve from a little above the lower border of the gluteus maximus muscle to the upper angle of the popliteal space. Should the injury be at a higher or lower level

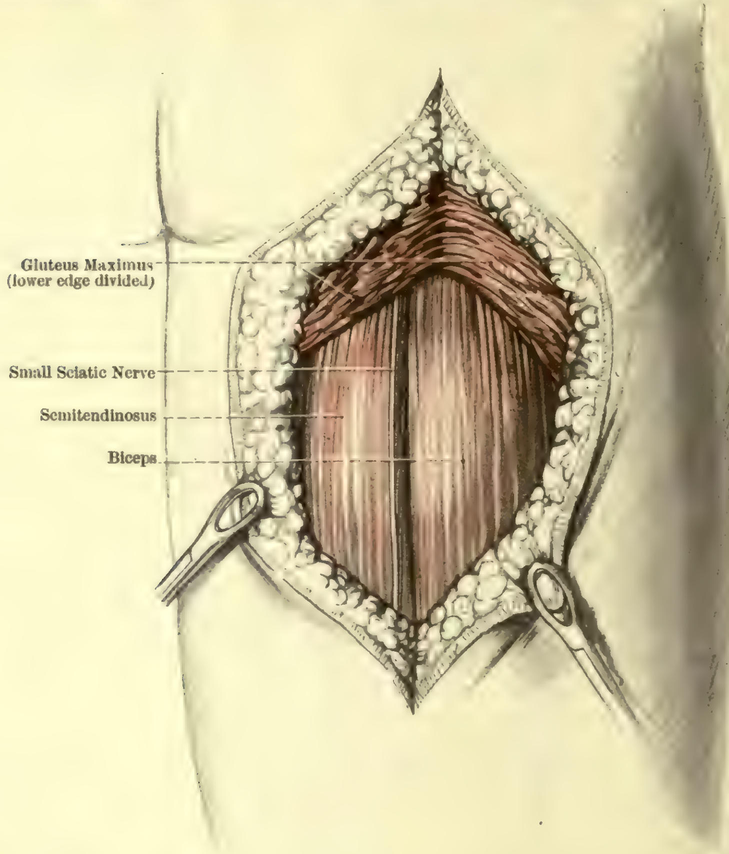


FIG. 110.—Exposure of sciatic nerve in upper third of thigh—septum found between biceps and semitendinosus.

than that selected the incision must, of course, be modified accordingly, so that the dissection may encroach either upon the buttock or upon the upper part of the popliteal space. If the incision is accurately placed, it will expose the interval between the fleshy bellies of the biceps and semitendinosus which are separated by a very delicate septum, for which the small sciatic nerve acts as a guide. When the fascia has been split, the small sciatic nerve and the terminal branch of the sciatic artery and its companion vein will be exposed. (Figs. 110 and 112.) The septum

between the above-named muscles is now opened up and their bellies are held well apart by suitable retractors. The great sciatic nerve lies deeply at the bottom of the wound on the dorsal surface of the adductor magnus. It is surrounded by an abundance of adipose tissue, ramifying in which are the muscular branches of the three perforating arteries of the profunda femoris and their companion veins. In applying hæmostatic forceps to

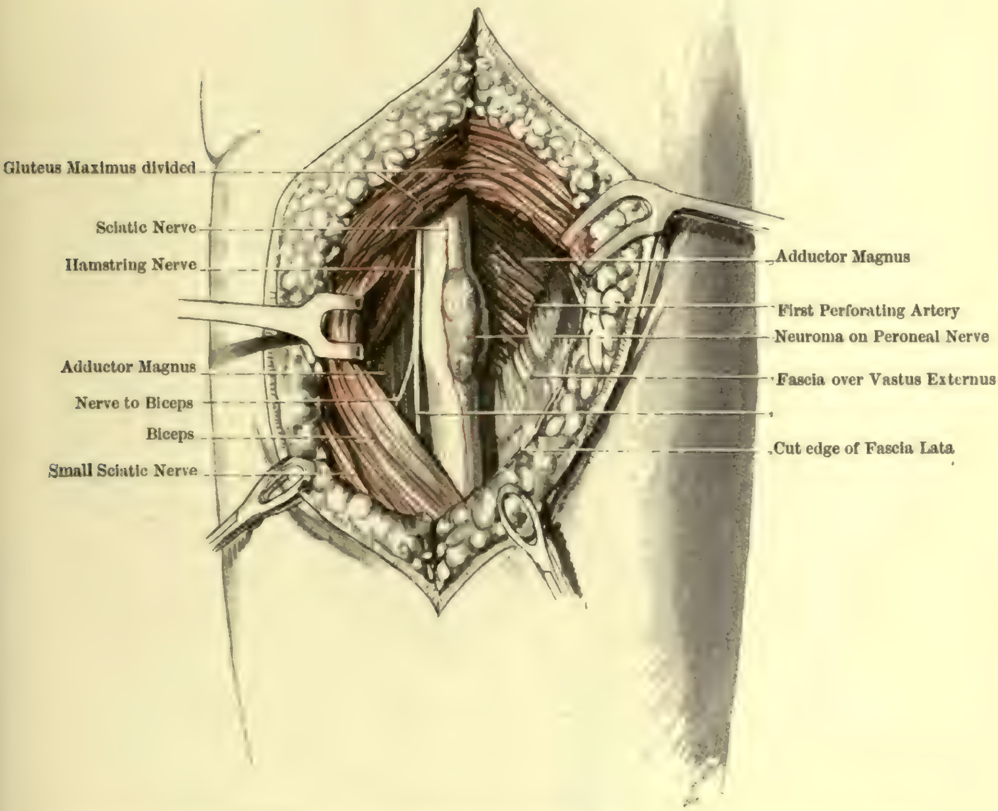


FIG. 111.—Operation for a neuroma involving the peroneal portion of the right sciatic nerve at the upper part of the thigh. The lower border of the gluteus maximus has been divided and the biceps retracted inwards.

these vessels care must be taken not to injure the motor nerves which generally accompany the vessels and enter the muscles along with them. Again, the motor nerves are less liable to be injured if the sciatic is first exposed well above the lesion and then carefully traced distally, a sharp look-out being kept for the branches as they arise.

The branches of the sciatic nerve to the hamstring muscles all arise

from the medial border of the nerve (tibial portion) with the exception of the branch to the short head of the biceps, which springs from the ventral aspect of its outer border about the middle of the thigh. (Fig. 113.) The branch to the upper half of the semitendinosus and long head of the biceps comes off at the junction of the upper and middle thirds of the thigh; the latter branch descends upon the dorsal aspect of the sciatic, which it crosses very obliquely. The branch to the lower half of the semitendinosus and to the semimembranosus come off at a lower level.

When the lesion lies *nearer the buttock*, the intermuscular septum between the biceps and semitendinosus muscles is split upwards into the substance of their common origin so as to separate the tendinous portion, which belongs to the biceps, from the fleshy portion, which is associated with the semitendinosus. Before this can be done it will be necessary to repeat the lower part of the dissection just described by prolonging the incision upwards so as to expose the nerve beneath the lower part of the gluteus maximus before it descends ventral to the biceps muscle. If now the lateral border of this muscle is well freed, it can be retracted either upwards and outwards or downwards and inwards as may be necessary. When this muscle itself is badly involved in scar tissue, it may be necessary to excise a portion of it. (Fig. 110.)

Before leaving this dissection, it is advisable to warn the beginner against the error of at first mistaking the ribbon-like tendon of the semimembranosus for the great sciatic nerve. This error is quite likely to happen in exposing the nerve in the proximal half of the thigh, after splitting up the septum between the biceps and the semitendinosus muscles. When this has been done, the tendon of the semimembranosus, and not the great sciatic nerve, will be the only structure exposed at the floor of the wound. This tendon, which is about the same thickness as the nerve, lies a $\frac{1}{4}$–$\frac{1}{2}$ in. medial to it, both descending parallel to one another upon the dorsal surface of the adductor magnus. If the biceps be retracted well outwards, the great sciatic nerve will be exposed and the error detected. (Fig. 112.) The mistake is easily avoided if the operator will first expose the upper and outer border of the biceps and then retract it downwards and inwards; when this is done, the nerve, and not the tendon, will be the first structure exposed.

In prolonging the dissection into *the upper part of the popliteal fossa*, the bulky substance of the distal half of the semimembranosus is freed and retracted well inwards, while the biceps is retracted outwards. This will expose the commencement of the tibial and peroneal divisions of the nerve, one or both of which may be injured along with the lowest part of the parent trunk. The tibial division, which is considerably the larger, descends vertically dorso-lateral to the popliteal vessels in the upper part of the popliteal fossa. The peroneal division, on the other

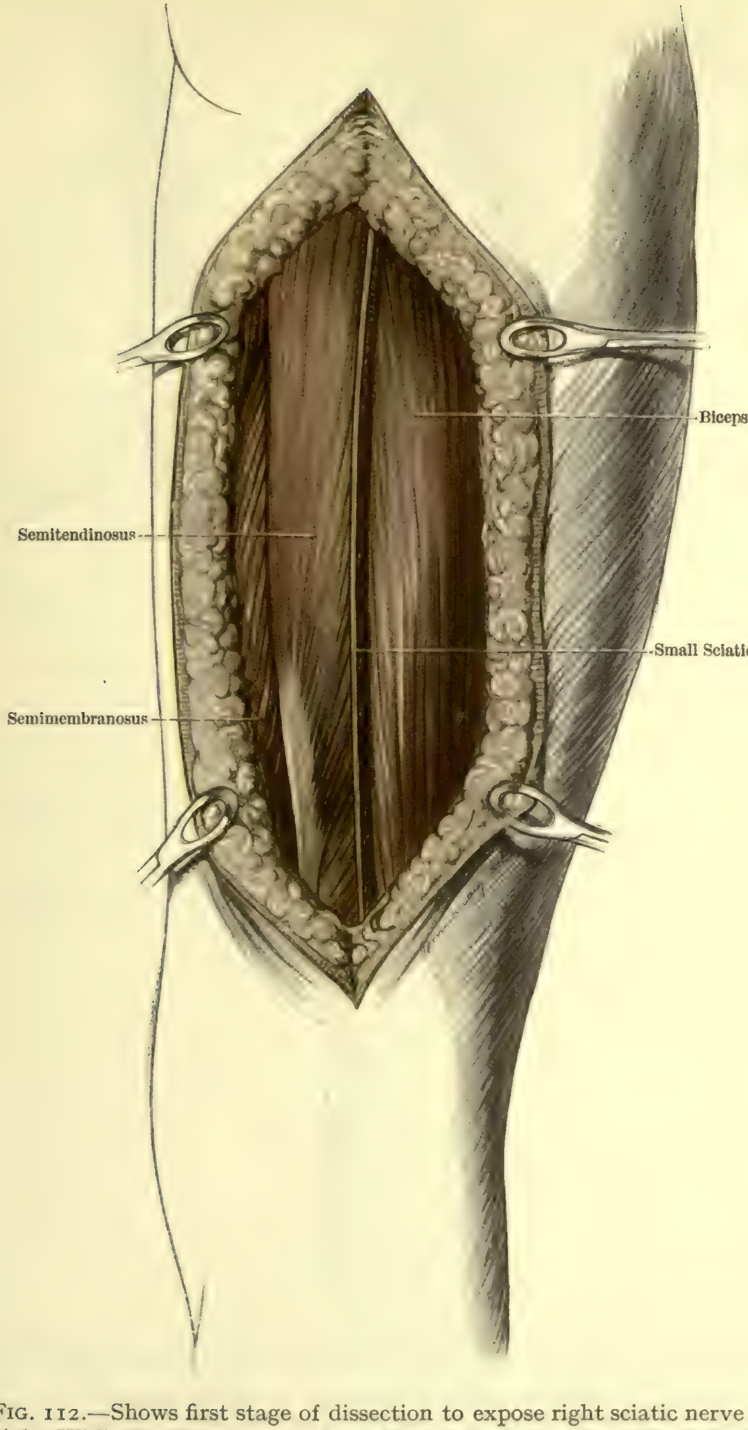


FIG. 112.—Shows first stage of dissection to expose right sciatic nerve in middle of thigh. While the N. cutaneous femoris posterior is a guide to the delicate septum between the biceps and semitendinosus muscles, the real guide to the interspace is obtained by noting the slight difference in the direction of the fibres of the two muscles.

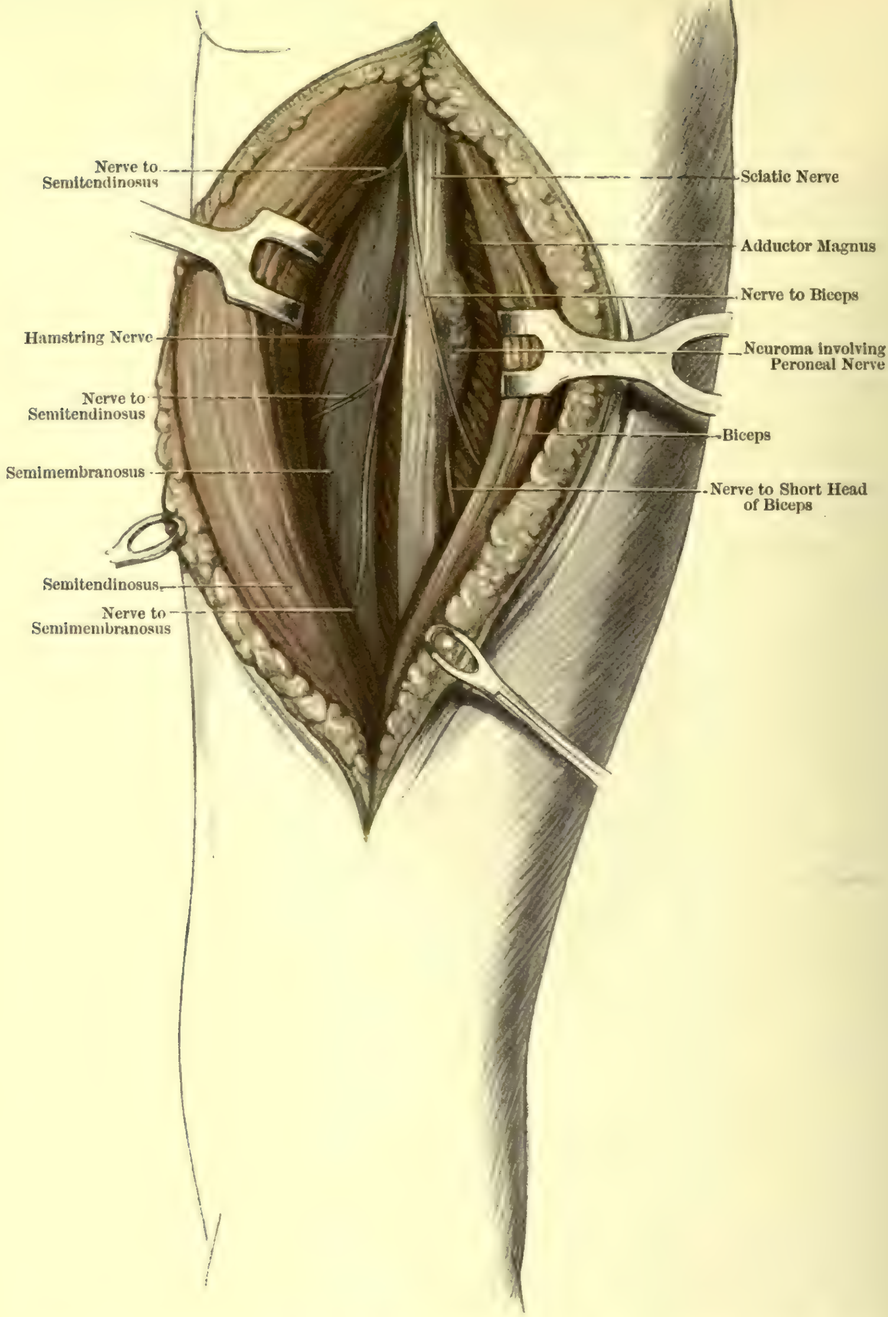


FIG. 113.—Second stage of operation shown in Fig. 111. Biceps retracted outwards, semitendinosus inwards. Neuroma involves peroneal portion of sciatic nerve. Nerves to hamstring muscles well seen. Note that the nerve to the long head of the biceps crosses the dorsal surface of the sciatic very obliquely, and that the nerve to the short head of the biceps arises separately from the lateral border of the peroneal portion of the sciatic. The tendon of origin of the semimembranosus muscle is seen lying medial and parallel to the sciatic nerve.

hand, diverges towards the head of the fibula and is overlapped by the biceps tendon.

If the nerve has been sutured, the knee must be kept flexed, the degree of flexion depending on the extent of the resection. To maintain the necessary position of the joint, a Jones double-gutter knee splint is employed and a metal club-foot shoe is applied to the foot to keep it at $< 90°$.

EXTERNAL POPLITEAL NERVE

(*Nervus Peroneus Communis*)

In operating on the external popliteal nerve, a sandbag should be placed under the shoulder and pelvis of the same side to enable the patient to be placed in the three-quarter prone position. A third sandbag is placed under the ankle, which should be so arranged that the dorso-lateral aspect of the knee is presented towards the operator. As in the case of the sciatic and internal popliteal nerves, an assistant should be detailed to maintain the leg at the necessary angle of flexion and rotation.

To lay bare the nerve, an incision is made from the upper angle of the popliteal space downwards and laterally along the medial border of the biceps to end a little below the neck of the fibula. When the popliteal fascia has been split, the proximal end of the nerve is exposed by freeing and retracting the lower part of the fleshy belly of the biceps, which overlies the nerve. The nerve is then exposed as it crosses the plantaris muscle. Lower down it crosses the outer head of the gastrocnemius, and in this situation it is very closely applied to the inner border of the biceps tendon. Both structures lie immediately beneath the popliteal fascia, which is here so thick and dense as to be almost aponeurotic in character. In many cases the injury has caused the nerve to be so firmly adherent to these structures by dense scar tissue that some difficulty may be experienced in isolating it, and not infrequently, the nerve is found to be completely destroyed for 2 or 3 in. When this extensive destruction extends so low down as to involve the commencement of its three divisions (recurrent tibial, musculo-cutaneous, and anterior tibial nerves) in the substance of the peroneus longus muscle, all idea of an end-to-end suture must be abandoned. Fortunately, the drop-foot which results from the paralysis of the extensor and peroneal muscles can be very satisfactorily dealt with by the operation of tendon suspension of the foot, a description of which will be found on p. 307. The communicans fibularis nerve, which descends vertically between the popliteal fascia and the outer head of the gastrocnemius, will frequently have to be sacrificed. This is a matter of no importance as it is a purely sensory nerve.

Provided a good distal stump of the external popliteal can be obtained, suture can be done in cases where there is a considerable gap between the nerve ends, because good relaxation can be obtained by flexing the knee and tracing the nerve up the thigh, if necessary as high as the buttock. In doing this it can be separated from the internal popliteal portion of the sciatic for the whole distance by splitting their common sheath. The only branch given off in the thigh from the external popliteal portion is one to the short head of the biceps, so that there is no contra-indication to this extensive dissection.

Fixation of the limb after operation is obtained by the methods employed for lesions of the sciatic nerve. When the knee has been extended and the patient begins to walk, it is necessary to fit the boot with an outside iron and inside T-strap, a stop-joint preventing plantar flexion of the foot.

INTERNAL POPLITEAL NERVE

In spite of the close relation of the internal popliteal nerve to the popliteal vessels, it is not infrequently injured without the vessels being involved. The injury may be due to a shrapnel wound which has only penetrated as far as the nerve or to a missile passing transversely through the popliteal fossa close to its roof. In other cases the nerve is compressed and stretched over the wall of a popliteal aneurism.

Exposure of the nerve in the upper part of the space has been dealt with in the description of operations on the sciatic in the lower third of the thigh. To expose the nerve in the *middle and lower divisions of the fossa*, an incision is commenced over the centre of the posterior aspect of the thigh at the junction of its lowest and middle thirds, and continues vertically downwards to the junction of the upper and middle thirds of the leg. The popliteal fascia is now split along the whole length of the fossa, and any portion of it which has become adherent to the subjacent structures should be dissected away. The external saphenous vein, which ascends in the superficial fascia covering the lower half of the space, should be freed and divided between forceps. If it is involved in scar tissue, care should be taken not to wound it just where it joins the popliteal vein. No attention need be paid to the terminal branch of the small sciatic nerve or to the communicans tibialis and communicans fibularis nerves as they are purely sensory, and if they are embedded in scar tissue it is better that the involved portions should be excised. The communicans tibialis nerve descends in the furrow between the two heads of the gastrocnemius, while the communicans fibularis descends on the dorsal surface of the outer head of that muscle. If these nerves are not involved in scar they are easily freed and drawn aside. The nerves to the gastrocnemius, one of which enters the dorsal surface of

each head of the muscle about 2 in. below its origin, along with its companion muscular artery, should, on the other hand, be preserved if possible. Traced upwards, these branches are found to be given off from the internal popliteal at the level of the upper border of the femoral condyles. It follows, therefore, that, when the lesion of the main nerve occupies the lower part of the fossa, these motor branches are not necessarily involved, and that by careful dissection they may often be preserved intact. (Fig. 114.)

The next step in the operation is the exposure and freeing of the internal popliteal nerve below the lesion. To do this, the two heads of the gastrocnemius muscle must be separated and well retracted, the plantaris muscle being freed and displaced along with the outer head. The nerve to the soleus is now seen descending immediately upon and dorsal to the internal popliteal trunk close to the medial border of the plantaris. At a little lower level, the muscle passes downwards and inwards between the two nerves. The branch to the soleus, however, is so closely related to the parent trunk that it is almost certain to be involved along with it. The plantaris muscle itself may be so implicated that a part of it may have to be resected.

The lowest part of the dissection involves the cutting across of the tendinous arch of the soleus as it spans the popliteal vessels and internal popliteal nerve, where they become continuous with the posterior tibial vessels and nerve. It is just at this level that the posterior tibial nerve gives off a muscular trunk which, after passing beneath the arch, immediately breaks up into a leash of branches for the supply of the three deep muscles of the calf. The highest branch supplies the tibialis posticus, which explains the escape of this muscle in some cases of complete division of the posterior tibial nerve high in the calf. If the lesion is at the lowest part of the popliteal space, the soleus must be split in a downward direction as far as is necessary (v. Posterior Tibial Nerve).

The most troublesome part of the dissection is generally the separation of the injured portion of the nerve from the subjacent popliteal vessels, more especially from the vein. In the middle of the space the nerve lies superficial (dorsal) to the vein ; while at the lowest part of the space it lies dorso-medial to the popliteal vessels. These vessels, even in the normal condition, are closely bound together in a common sheath. Fortunately the vein is almost as thick-walled as the artery. Troublesome bleeding is liable to occur when the vessels are implicated in the scar tissue. The vein may have to be ligatured, but great care should be taken to avoid wounding the artery.

A drain may have to be introduced down to the floor of the space, but it should be omitted if possible. If the popliteal fascia is intact it may be brought together by a few interrupted catgut sutures ; frequently,

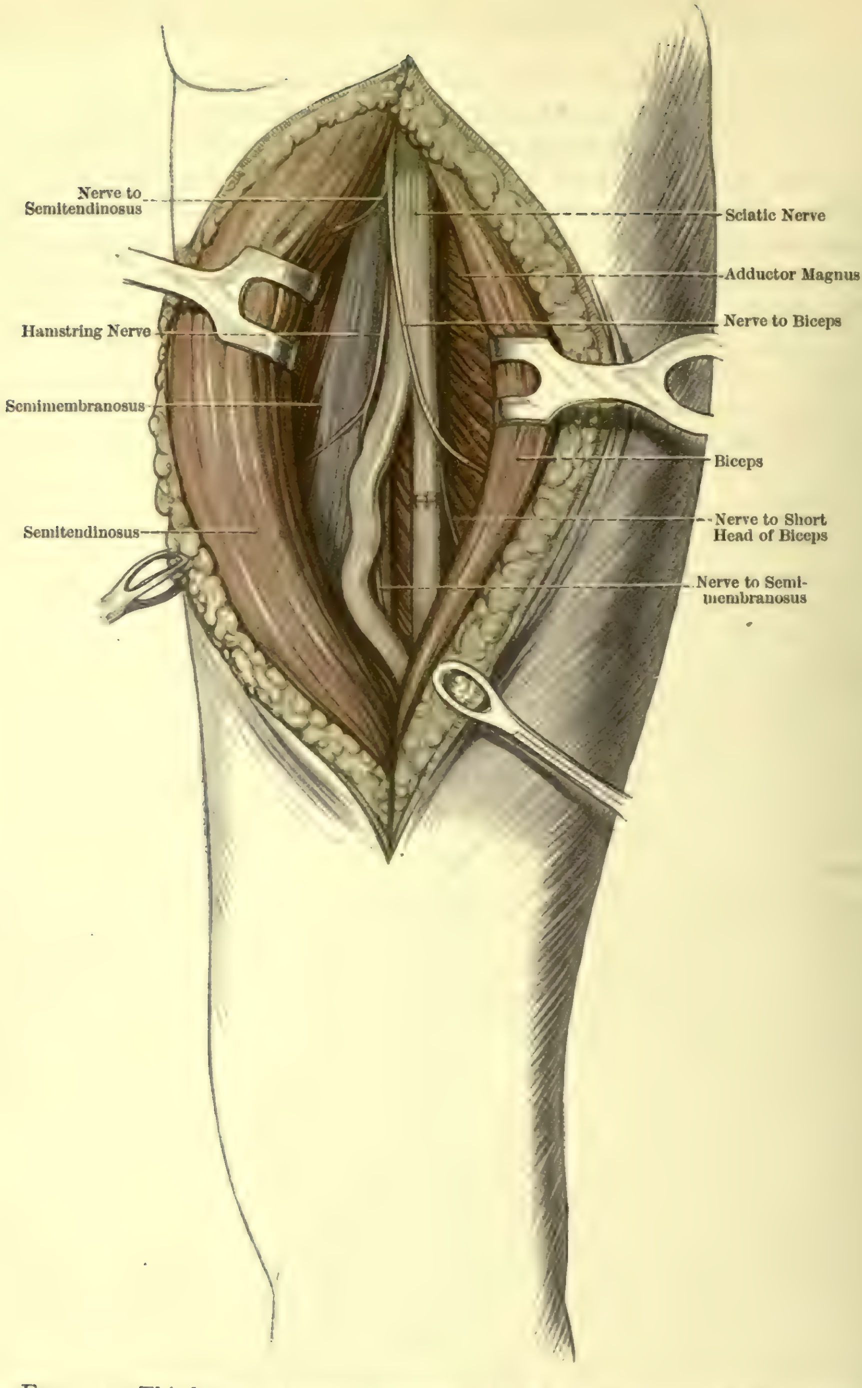


FIG. 114.—Third stage of operation shown in Figs. 111 and 112. he sciatic nerve has been split longitudinally, the neuroma which involved its peroneal portion has been resected and the stumps sutured with fine linen thread. Note the apparent lengthening of the tibial portion of the nerve.

however, enough of the fascia has to be removed to prevent its edge from being approximated.

Fixation of the limb after operation is obtained by the methods employed for sciatic nerve lesions. When the knee has been extended and the patient begins to walk, his boot should be fitted with an inside iron and an outside T-strap ; the iron should have a stop-joint to prevent dorsiflexion of the foot.

POSTERIOR TIBIAL NERVE

In the writer's experience the posterior tibial nerve has furnished only 6 per cent. of the operations on the nerve trunks of the lower extremity. While this is the case, it should be remembered that patients themselves often do not notice partial anæsthesia of the foot and weakness of its intrinsic muscles, as they would do at once in a corresponding lesion of the hand. The objective signs, such as clawing, trophic ulcers and atrophy of the sole muscle, are late in developing and are very variable in their degree of severity, so that in some cases of complete division of the nerve, they will only be noted after careful examination. If all cases of wounds of the leg are examined for symptoms of nerve injury within the first two weeks, some involvement of the posterior tibial will be found in a large proportion of cases. In many, of course, spontaneous recovery occurs.

In the upper two-thirds of the leg, the posterior tibial nerve is deeply placed beneath the gastrocnemius and soleus muscles, where it occupies, along with the posterior tibial vessels, a special compartment of the fascial septum which intervenes between the superficial and deep muscles of the calf of the leg. While the nerve, like the artery, may be approached either through a mid-dorsal or an internal incision, there can be no question that in the case of the nerve, the former is much the better route as it allows the nerve to be more directly and more freely exposed and to be more easily drawn up into the wound during the suturing. Much of the difficulty will be overcome if the operator does not hesitate to make the wound of sufficient length to allow of adequate retraction of the superficial muscles.

The incision should extend from a little below the middle of the popliteal space down the mid-dorsal line of the limb with a slight deviation inwards as far as the junction of its middle and lowest thirds. The terminal branch of the small sciatic nerve may be ignored, but the other structures which occupy the line of the incision, namely the external saphenous vein, the communicans tibialis, and communicans fibularis nerves, which, at the lower part of the wound, have joined to form the external saphenous nerve, are freed and drawn outwards or, if involved in scar tissue, are

resected. The incision is deepened in the upper part of the wound in the interval between the two heads of the gastrocnemius, and below this level the muscle is split down the middle and the cut is prolonged still farther downwards, so as to bisect the tendinous portion to within a few inches of the heel. As these cases are not infrequently complicated by equinus, this procedure allows the surgeon to complete the operation by a Z-shaped lengthening of the tendo Achillis. The two halves of the muscle having been retracted, the wound is deepened so as to split also the subjacent soleus muscle, care being taken to preserve the motor nerve which enters its dorsal aspect close to the upper border of its outer head. In splitting the muscle, the operator should bear in mind its great thickness, and when the knife has penetrated half its depth, he should be prepared to see the flattened tendinous intersection which occupies the whole width of the muscle. The fibres which spring from the dorsal aspect of the intersection pass downwards and backwards, while those which spring from its ventral aspect proceed downwards and forwards, the result being that along the middle of the cut surface of the muscle there is exposed the cut edge of the tendinous insertion with fibres radiating from it in a bipenniform manner. It is necessary to call special attention to this tendinous sheet in the substance of the muscle, otherwise the operator is liable to mistake it for the fascial layer which lies beneath the muscle and covers the deep flexors. When the whole thickness of the soleus and the upper part of the tendo Achillis has been split, the two halves are firmly retracted so as to expose the above-mentioned fascia. (Fig. 116.) By splitting this fascia a little internal to the medial border of the flexor longus hallucis muscle, opposite the middle of the calf, the posterior tibial nerve will be at once exposed with the posterior tibial artery and its venæ comites lying in close relation to its medial edge. The nerve is now freed in both directions. In doing this, some trouble may arise from the muscular branches of the posterior tibial vessels, and especially from the veins where they join the venæ comites. When the upper part of the nerve is reached, it will be found to lie in the interval between the posterior tibial artery and its large peroneal branch, while higher up still it lies directly upon, that is to say, dorsal to, the posterior tibial artery just where the peroneal artery is given off. It is here especially that the field of operation may be obscured by bleeding from the venæ comites. The peroneal vessels are so closely applied to the bone that if they are injured they are difficult to secure except by a stitch. To follow the nerve upwards into the popliteal space, the tendinous arch at the upper border of the soleus must be divided. The motor nerves to the deep muscles of the calf frequently spring from a common trunk which arises a little above this arch. The main branch to the flexor longus hallucis accompanies the peroneal artery ; a small branch comes off at a lower level for the supply

of the distal half of the muscle. The tibialis posticus also receives a second branch in the lower half of the leg. If the nerve is firmly adherent in scar tissue, either the posterior tibial or the peroneal artery may have to be ligatured. As the wound is a very deep one, all bleeding should be carefully arrested before the nerve is sutured. It may be necessary to

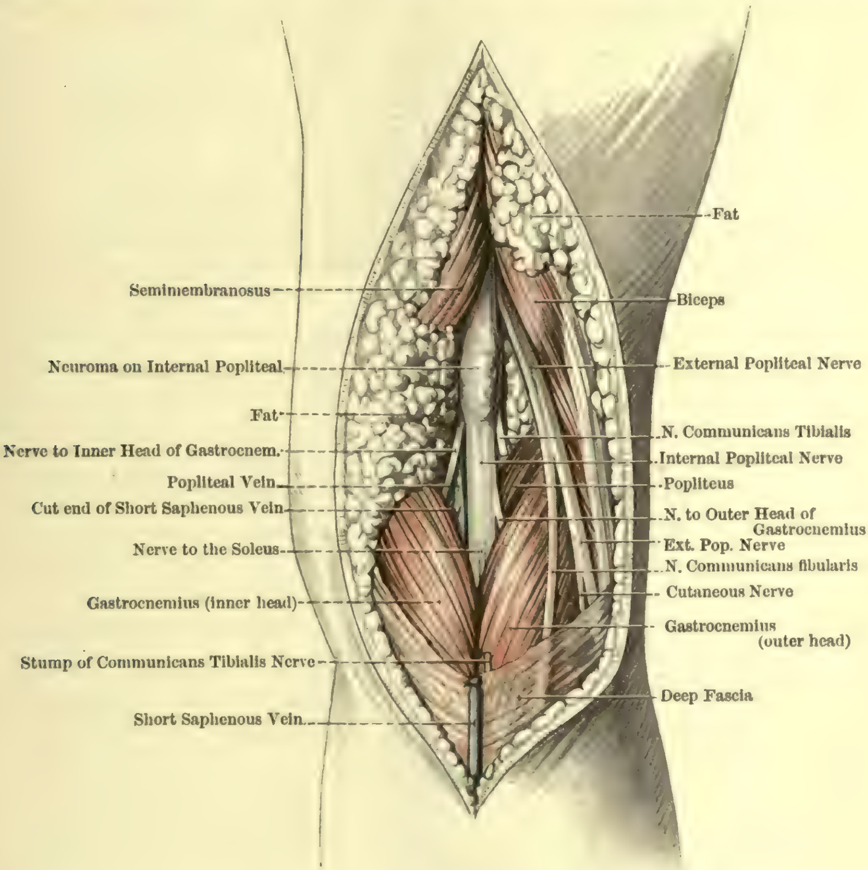


FIG. 115.—Operation for neuroma of internal popliteal (tibial) nerve.

introduce a drain. In the upper part of the wound, the split soleus and gastrocnemius muscles are sutured independently; while in the lower half, where they join to form the tendo Achillis, only one row of sutures is employed.

If much of the nerve has been resected it will be necessary to plantar flex the foot as well as flex the knee. If the foot is brought gradually back to a right angle before commencing to straighten the knee, there will be no necessity subsequently to lengthen the tendo Achillis to allow

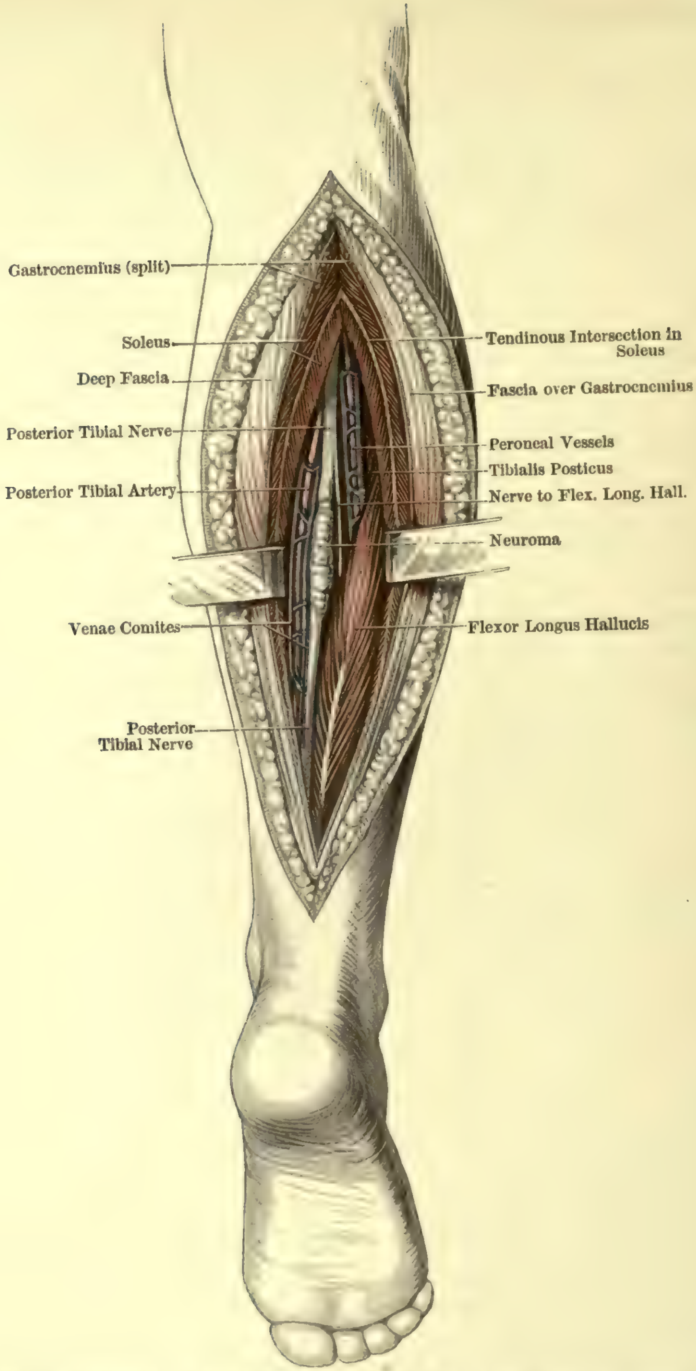


FIG. 116.—Operation for the exposure of a lesion of the posterior tibial nerve in the middle third of the leg. Gastrocnemius and soleus muscles split through a long median dorsal incision; tendinous intersection of soleus well seen. Note the relation of the posterior tibial nerve to the main vessels and to the flexor hallucis longus muscle.

the foot to be dorsiflexed after the nerve is united. A 3-in. gap can be overcome by flexion of the knee alone if the internal popliteal nerve is freed up into the lower third of the thigh, care being taken to dissect up the branches to the superficial muscles of the calf.

In exposing the *posterior tibial nerve in the lowest third of the leg* the incision should run parallel to the medial border of the tibia midway between it and the tendo Achillis. The internal saphenous vein and nerve lie in the subcutaneous fat at the medial edge of the wound. After the strong deep fascia has been divided, a still deeper layer is exposed; it extends laterally between the tendo Achillis and the deep muscles. To lay bare the posterior tibial nerve, the operator should keep the edge of the knife directed towards the latter muscles so as to divide this deeper layer of fascia which forms their immediate covering. The incision should be made behind and lateral to the neuro-muscular bundle so as to avoid injury to the venæ comites which lie internal to the nerve. In the upper part of the wound, the fleshy medial border of the soleus must be retracted well outwards, when the nerve will be found in the interval between the adjacent borders of the flexor longus digitorum and the flexor longus hallucis muscles, both of which are here still fleshy. The tibialis posticus muscle, being overlapped by the above muscles, does not come directly into view. Near the ankle the flexor longus hallucis is still fleshy, while the tibialis posticus and flexor longus digitorum muscles are represented by their tendons, both of which lie antero-internal to the nerve in close relation to the medial border of the tibia. The posterior tibial vessels lie between the two tendons and the nerve, but closer to the latter. The calcanean branch, which supplies the heel and adjacent part of the sole of the foot, should be spared if possible; it arises from the posterior tibial a little above the upper border of the internal annular ligament.

NERVE INJURIES IN THE FOOT

Operations for nerve injuries in the foot are less frequently necessary than in the case of the hand. If the original injury is extensive, operative treatment of the nerve lesion *per se* is not practicable. In localized lesions, operation may be called for to relieve pain or tenderness due to the implication of the nerve in scar tissue or for the removal of a foreign body—a piece of khaki cloth in one case—which has implicated the nerve.

In other cases, exploration is indicated for the cure of a trophic ulcer. The plantar nerves may be implicated at or near their origin, and in this situation a successful resection may sometimes be carried out. The branches to the toes seldom call for operative measures except when they are involved in a painful scar.

To expose the terminal portion of the posterior tibial nerve and the commencement of the plantar nerves, an incision is begun well above

the ankle-joint and carried down nearly one finger's-breadth behind the posterior border of the internal malleolus and thence across the abductor hallucis muscle to the internal intermuscular septum. The internal annular ligament and deep fascia having been divided in the line of the incision, the posterior tibial nerve is found lying between the posterior tibial vessels and the tendon of the flexor longus hallucis. To follow the plantar nerves into the sole, the upper and lower borders of the abductor hallucis muscle are freed and the muscle is either retracted downwards or completely divided, according to the position and extent of the lesion. To expose the internal plantar nerve farther forwards the incision is made along the line of the internal intermuscular septum.

ANTERIOR CRURAL NERVE

It may be stated at once that complete paralysis of the anterior crural nerve is rarely met with, its short course in the thigh as an individual trunk accounting for this. Again, a wound of any severity in this locality would be very apt to cause damage to the femoral vessels, amputation or death from hæmorrhage resulting. Incomplete paralysis from a grazing type of wound is the more usual occurrence from injury to one or more of the individual muscular branches ; again, in certain cases of extensive laceration of muscles with subsequent scar formation on a large scale, the direct muscle involvement may be as much responsible for the clinical findings as the injury to the nerve itself.

While exploration of the nerve is indicated for a partial lesion which is not recovering or for the relief of pain, actual resection is rarely possible on account of the leash of branches into which the nerve breaks up. Transplantation of the biceps cruris and gracilis or semitendinosus, preferably the former, into the periosteum of the patella is the best procedure in such cases.

PROCEDURES WHEN END-TO-END UNION CANNOT BE EFFECTED

NERVE GRAFTING

When all efforts to obtain end-to-end suture have failed, the gap may be bridged by means of a portion of a sensory nerve, the largest available being used, either as a single or a multiple cable. The internal cutaneous of the arm may be sacrificed and in some cases its calibre is almost equal to that of the ulnar. Unfortunately, it is usually injured by the same lesion which destroyed the median or ulnar ; it may also bifurcate at a higher level than usual, in which case the trunk may be too short. The

dissection for the exposure of the internal cutaneous nerve is described along with operations upon the median and ulnar nerves in the upper arm.

A nerve which is very suitable for grafting purposes is the cutaneous portion of the musculo-cutaneous nerve in the leg. It is exposed by an incision along the middle third of a line extending from the anterior border of the head of the fibula to a point one finger's-breadth in front of the external malleolus. This incision exposes the septum between the peronei and extensors; the nerve, after piercing the septum very obliquely, becomes subcutaneous at the junction of the middle and lower third of the leg. The nerve measures about 6 in. from the point where it leaves the motor branches to the point where it bifurcates. Quite exceptionally it may be convenient for grafting purposes to utilize either the external cutaneous nerve of the thigh or a portion of the long saphenous nerve below the knee.

The graft is fixed in position by means of one or two retaining sutures of No. 160 linen thread which pass through the sheaths of the graft and prepared stumps. Care is taken that the graft is not subjected to undue strain.

Only six nerve-grafting and two flap operations have been done at the Edinburgh War Hospital and particulars of these are given in the table on p. 224.

In one case, where there was only the scantiest evidence of nerve regeneration, the nerve was explored again and the graft was found to be shrunken, and flattened and fibrous-looking. The whole graft and its junctions with the ulnar were removed and prepared for microscopic examination. A fresh graft from the musculo-cutaneous of the leg was put into the ulnar.

In one of the two cases in which satisfactory return of function has occurred after nerve grafting (i. e. into the median), the question of an abnormal ulnar distribution cannot be wholly excluded. The clinical evidence in all the other cases points to an arrest of the advance of the growing axones at the distal junction of the graft with the main nerve, which could easily be explained by a development of scar tissue at the distal suture line before the axones reached it. If this be the case, it would be a logical procedure to explore the distal junction of all grafts when the distal tingling has ceased to extend beyond it. The further progress towards recovery is no doubt due to the fact that the growing axones have been unable to penetrate the sclerosed barrier which has developed at the distal junction.

The partial but very incomplete recoveries indicated in the table are accounted for by the successful penetration of a few nerve fibres through the sclerosed distal junction.

Nerve.	*Gap.*	*Operation.*	*No. of Cases.*	*Time observed after Operation.*	*Evidence of Recovery.*
Median in forearm.	$3\frac{1}{2}''$	Graft from internal cutaneous of arm (in one 2-ply)	2	(*a*) 6 weeks (*b*) 15 months	i. Return of pressure and joint sense in the median distribution. ii. Distal tingling down to hand. iii. Trophic improvement. iv. A doubtful voluntary contraction of opponens and abductor pollicis brevis. v. Doubtful faradic response in the same.
Ulnar in forearm	$3\frac{1}{2}''$ $6''$	Single graft from internal cutaneous	2	(*a*) 2 years (*b*) 13 months	Distal tingling to wrist. Return of pressure sense. Distal tingling to wrist. Hypothenar tenderness. Nerve explored and kept for section.
Ulnar Median	$4\frac{1}{2}''$ $4''$	Musculo-cutaneous from leg	1 1	1 year 5 months	Faradic response in all small muscles but no other evidence of recovery reported by National Orthopædic Hospital, London. Not seen again.
Median		Flap turned down from proximal end	1	$1\frac{3}{4}$ years	No evidence of recovery (trophic sores). Exploration advised and refused.
Ulnar			1	2 years	i. Return of pressure sense. ii. Tenderness of ulnar intrinsic muscles. iii. Distal tingling to lower end of graft.

The alternative procedure, of turning down a flap from the proximal end of the injured nerve, is not to be recommended because it increases the distance which one-half of the growing axones have to traverse and it fails to provide a bridge equal in calibre to that of the injured nerve. To turn up a flap from the distal segment is not advisable if it entails, as it frequently would, the sacrifice of important branches.

In cases of very extensive lesions of the sciatic, especially where stiffness of the knee-joint prevents relaxation of the nerve by flexion of that joint, it may be advisable to bridge the more important tibial portion of the nerve by sacrificing a corresponding length of the peroneal portion for use as a graft ; in some cases a double-ply graft can be taken from the peroneal portion, half being obtained above, and half below the lesion. This is desirable as the tibial portion is usually twice the diameter of the peroneal nerve. The permanent foot-drop resulting from sacrifice of the peroneal portion of the nerve can be treated by a foot-slinging operation, done later. The sensory loss from destruction of the peroneal nerve is

FIG. 117.—To illustrate functional disability in combined paralysis of lumbricæ and interosseous muscles in cases where median and ulnar nerves are both involved.

of little importance. Everything should be done to secure recovery of the tibial portion of the nerve, as its paralysis is serious, from its tendency to be complicated by disabling trophic ulcers on the sole of the foot.

BONE SHORTENING

Shortening of the femur has been done as an adjuvant to approximation, where stiffness of the joints in extension prevents immediate relaxation or slow stretching of the nerve. Stiffness of neighbouring joints is a serious complication of extensive nerve injuries. When the elbow is the joint involved, a preliminary arthroplasty is sometimes advisable. This is not to be considered in the case of the knee, but, as an alternative, shortening of the femur is justifiable in certain cases.

Sir Robert Jones recommends a transverse osteotomy followed by lateral displacement of the fragments. Later on, when recovery is advancing, the bone is gradually lengthened again.

In most cases, shortening of the humerus is to be preferred to an arthoplasty of the elbow ; this procedure is especially applicable when, along with the nerve lesion, there is also an ununited fracture of the humerus.

The humerus may be shortened to the extent of two inches, or even more, without serious disability. To ensure subsequent union in good

position it is advisable to wire the fragments after they have been dovetailed by the step method.

In cases of extensive nerve destruction in the forearm, complicated by non-union of one or both bones, shortening of the forearm is also to be recommended, the bones being dealt with at a preliminary operation and the nerve sutured at a subsequent date. Even in cases where the nerves of the forearm have been extensively destroyed it will be found that an end-to-end approximation of the stumps can almost invariably be effected if the procedures recommended in this article be adopted. The writer has not found it necessary, therefore, to shorten the bones of the forearm in cases in which they have been uninjured. In this connexion, too, it may be mentioned that the writer, on two occasions has been able to effect an end-to-end suture of the stumps in patients who had previously undergone a nerve-grafting operation on the supposition that a direct end-to-end approximation was impossible : the suspicion that it *was* possible, was aroused by the comparatively short incision which had been employed at the original operation.

NERVE TRANSPOSITION

What is known as nerve transposition constitutes one of the most effective aids in obtaining end-to-end union of a divided nerve, after extensive resection has been performed. By the term is meant the alteration of the anatomical course of the nerve, so that it is made to pursue a straighter and consequently a shorter course. The nerve is made to run across the flexor aspect of the joint so that full benefit may be derived by flexion. The method is only applicable in dealing with the ulnar and musculo-spiral nerves. In the case of the ulnar, the nerve is made to pursue a course in front of the elbow-joint instead of behind it, so that it runs almost parallel to the median nerve. Flexion of the elbow-joint then reduces the gap between the divided ends by 2 to 2½ in., whereas if the nerve be left in its normal position flexion of the elbow would increase the gap. With regard to the musculo-spiral nerve, while only 1 in. is gained by the transposition, this amount may in certain cases make all the difference between the ability or failure to obtain end-to-end union.

The details of technique for the method will be found in the sections dealing with the individual nerves.

I desire to express my indebtedness to Captain W. A. Cochrane and Dr. Maud F. Forrester-Brown for reading the proofs of this article as well as for their useful suggestions during its preparation. The illustrations have all been made from drawings done at the time of operations either by the artist himself (Mr. J. T. Murrary) or by Dr. Forrester-Brown.

THE POST-OPERATIVE TREATMENT OF PERIPHERAL NERVE INJURY

BY

MAJOR ROWLEY BRISTOW

THE POST-OPERATIVE TREATMENT OF PERIPHERAL NERVE INJURY

THE after-treatment of cases of peripheral nerve injury must be considered under two headings: (*a*) Immediate, and (*b*) Remote After-treatment.

IMMEDIATE

For the first two weeks the process of healing of the nerve dominates the situation.

The treatment consists in rest, with the affected muscles relaxed, and the joints fixed in the necessary positions. **Rest** is essential until the wound has healed, and until the sutured nerve has united. Rest in the appropriate position, as regards the limb, is the first essential in the post-operative care of these cases.

No meddlesome therapeutical measures must be permitted until the necessary period has elapsed, nor must any stretching with possible damage therefrom be allowed to throw strain on the newly-joined nerve. If, however, the median and ulnar nerves have been sutured in the arm, passive movements of the fingers should be commenced after a few days' rest. Attention will be directed to the tendency to stiffening of the hand after an injury to one or both of these nerves, and every effort must be made to prevent it from the earliest possible moment.

In cases in which neurolysis, with freeing of the nerve from scar tissue without suture has been performed, rest is still essential, but not for so long a period.

In simple, uncomplicated cases, after having freed or sutured the nerve, ten to fourteen days' absolute rest should be allowed for the part.

The principle on which the following details are based is that of maintaining the paralysed muscles relaxed, so far as is compatible with keeping the joints supple and of allowing them to be exercised to a full range of movement, and so hastening their recovery and preventing contracture, by either:

(1) Overaction of the non-paralysed opponents;

(2) The force of gravity.

Posture. The position of the limb is discussed for each individual nerve under ' Remote After-treatment '.

The following suggestions regarding the time necessary to retain the position fixed upon by the surgeon at the time of operation are indicated, to serve as a rough guide, and will vary in individual cases.

Lesions of the Brachial Plexus, C.V. VI. The arm will be held abducted with the elbow flexed, and will remain in this position until recovery ensues and the nerves are again able to conduct impulses.

Median and Ulnar Nerves in the Arm. After suture, in the majority of cases the part will be put at rest with the elbow fully flexed, and the arm adducted and bandaged to the chest wall. This is the position which allows the most complete approximation of the divided ends in cases in which suture has been performed. After the first few days, the hand should be left free, and the fingers moved through their full range daily.

It is important to remember the necessity for adducting the arm. The position should be maintained for from two to three weeks, when the arm may be allowed to be free from the side, the elbow still remaining flexed.

After a further two weeks flexion may be gently relaxed, the arm being allowed free movement at the elbow in six to eight weeks after suture of the nerve.

Median and Ulnar Nerves in the Forearm. For about six to eight weeks flexion of the elbow- and wrist-joints will be needed, in cases in which suture has been carried out, if there has been destruction of the nerve and some consequent tension.

Musculo-Spiral Nerve. The arm will be put up with the elbow flexed and held by a ' collar and cuff ' or similar sling. The wrist and hand will be immobilized on a long ' cock-up ' splint, slightly flexed at the metacarpo-phalangeal articulation.

This position should not be maintained for longer than two to three weeks, or the hand will tend to stiffen. The wrist-joint will not suffer, but the metacarpo-phalangeal and inter-phalangeal joints require movement in order to maintain their free mobility. This point is discussed more fully when considering ' Remote After-treatment '.

Sciatic Nerve. Extension of the hip-joint with flexion of the knee is the position which allows the greatest relaxation of the nerve, and is therefore necessary in those cases in which there has been much destruction of nerve tissue and difficulty in bringing the ends into apposition.

A single Thomas hip-splint, bent to an acute angle at the knee, is a convenient splint to maintain the necessary position.

The affected limb will hang over the side of the bed, the foot being supported on a footstool or pillow. A right-angled foot-splint, a club-foot shoe or similar appliance, holds the ankle-joint in slight dorsi-flexion.

The position is irksome, but it must be maintained for two or three weeks if there is any possibility of tension after the suture. After this the splint is removed, and the knee maintained in full flexion on a bent iron splint.

After a further two weeks, i. e. a month after the operation, the knee can be allowed to relax from full flexion to 90°. Two weeks later it may be allowed 45° more freedom, and finally eight weeks after operation the splints, with the exception of the right-angled foot-splint, may be discontinued.

In cases in which there is but little destruction of the nerve, and suture is easily performed and no tension occurs, it will not be necessary to maintain the hip extended. A simple posterior splint holding the knee flexed will suffice, and this position is more comfortable for the patient.

REMOTE AFTER-TREATMENT

After the wounds have healed, and with the reservation as regards position alluded to in the preceding paragraphs, the general lines of after-treatment of peripheral nerve injury must be considered under the following heads :

Postural : by splintage.
Nutritional : by (1) Heat ;
(2) Electrical stimulation ;
(3) Massage ;
(4) Remedial exercises ;
(5) Re-education.

It is probable that the time taken for regeneration of axis cylinders is not affected by any specific method of treatment, electrical or otherwise, and the treatment is directed to maintaining or regaining nutrition and function in the muscles and joints supplied by the damaged nerve.

Unless this treatment is carried out satisfactorily over a period necessarily long and measured by months, the functional result is endangered.

It is true that cases are met with which have recovered function in spite of little or nothing in the way of after-treatment, but again it is not uncommon to come across patients in whom the nerve has recovered its power of conduction, and in whom there has been no recovery of power over the affected part.

The principle that a paralysed muscle must be placed and maintained in the relaxed position, and never for a moment allowed to be stretched, must be modified in certain cases.

Although it is always desirable to maintain a paralysed muscle in the relaxed state by splinting, it is of paramount importance at this stage

of treatment that the peripheral portion of the limb supplied by the nerve should be kept in a supple and non-contractured state, even if some stretching of the paralysed muscle is caused thereby. This is particularly true in cases of median and ulnar suture. It is the lesser evil.

In the case of a lesion of the musculo-spiral nerve, if the hand is maintained in dorsiflexion without movement for a period longer than about a month it will get stiff.

This stiffness is noticeable at the metacarpo-phalangeal joints in the position of extension. If the position of extension of these joints has been maintained for months, the stiffness will be difficult to overcome; moreover, extension of phalanges should never be complete.

Stiffness must be anticipated and prevented by daily moving these joints through their full range. The inter-phalangeal joints also require daily movement, to prevent troublesome stiffness.

The joints of the hand are the only ones that give trouble from stiffness after nerve suture. If, for example, the position of relaxation is maintained, by holding the wrist dorsiflexed, there is no difficulty afterwards, and the power of flexion in this joint comes back with use, and no special treatment is necessary. So with the ankle-joint: prolonged fixation in slight dorsiflexion in lesions of the external popliteal nerve does not in practice cause a fixed deformity.

Lesions of Upper Part of Brachial Plexus—or of the Circumflex Nerve. The arm must be maintained in the abducted position to allow of relaxation of the deltoid and to avoid adduction deformity due to the unopposed action of the pectorals, latissimus dorsi, &c. The splint must be worn night and day, and it is better that the arm should never be dropped to the side.

With recovery the splint is gradually lowered, and finally discontinued.

The test of recovery is simple. The splint is first lowered some 20°, and if the patient can voluntarily abduct his arm to the original position, and does not lose this newly-acquired power—all is well. The splint is further lowered every few days, then left off at night and finally discontinued altogether. If the power of abduction is lost, the splint must be re-applied, until the patient is able to satisfy the conditions of the test of recovery.

All treatment directed towards aiding nutrition can take place with the splint applied, or if desired, with the arm held abducted by the masseuse.

Freedom of movement upwards, and of rotation, is maintained by daily manipulation, but the arm should not be lowered, and there is no risk of a fixed deformity in the abducted position.

This position is exceedingly irksome, and if the patient is not willing to submit to it, it is better to compromise. The weight of the arm may be taken by a sling supporting the elbow, and so preventing the drag on

the ligaments and muscles of the shoulder, whilst the arm is held adducted in line with the chest wall.

Lesions of the Musculo-Cutaneous Nerve. The elbow is maintained in the flexed position by means of the 'collar and cuff'.

Lesions of the Median and Ulnar Nerves. In an uncomplicated case, after the necessary period of relaxation during which the nerve is healing, there is no need for any special splintage.

In my experience, the movement of the hand and the auto-massage so produced is of advantage. A hand of which any part of the nerve supply is damaged, tends to stiffen if kept at rest, and so the advantage of keeping the small muscles relaxed is out-balanced by the disadvantages.

To keep the median muscles relaxed, it would be necessary to flex the wrist-joint, to flex the first finger and the thumb, and also to oppose the latter to the palm, but this is not advisable.

The deformity of the hand produced by a lesion of the ulnar nerve, the *main en griffe*, can usually be prevented by attention to the muscles and manipulation of the joints.

If the 'clawing' shows signs of commencing, it will generally be restricted to the fourth and fifth fingers. Straight finger-splints, prolonged well up the palm and holding the metacarpo-phalangeal joints slightly flexed, and the inter-phalangeal joints extended, will be necessary. They should be worn at night and discontinued during the day, when the full use of the hand should be allowed.

If the onset is not stayed, the splints must be worn night and day for a time.

In a certain proportion of cases after recovery from an ulnar lesion, the hand shows abduction deformity of the little finger. A small piece of adhesive strapping fixing the little to the ring finger, will obviate this.

Combined Median and Ulnar Lesions with Ligation of the Brachial Artery. With this complication, the tendency to stiffness of the whole hand is very marked, and once stiffness has supervened it is extremely difficult to combat. Free mobility of the hand and fingers should be maintained throughout treatment, and no fixation adopted.

This stiffness is especially noticeable in lesions in the upper arm. The trophic fibres leave the nerves above the elbow, passing thence to the muscle-sheaths and tendons, in which they travel towards the periphery. Hence, it follows that they may escape in a low lesion, but are usually affected in wounds of the upper arm.

Lesions of the Musculo-Spiral Nerve. After the wound has healed, the most satisfactory type of splint is one which holds the wrist fixed in dorsiflexion, but allows movement of the fingers and thumb; for

FIG. 118.

FIG. 119.

FIG. 120.

simplicity and effectiveness I prefer the one figured in the illustration (Figs. 118, 119, and 120).

The tension of the elastic is such, that when the flexor muscles are relaxed the joints are extended, but when the flexors are used voluntarily the resistance is overcome, and the hand can be closed.

It is essential to keep the thumb extended, as the thumb extensors are the last muscles to recover in an injury of this nerve, and full controlled movement of the thumb is essential to a good hand.

The Sciatic Nerve. After the period of healing, in a lesion of the sciatic trunk, or its external popliteal portion, it is necessary to maintain dorsiflexion of the foot.

Two splints are required:

(1) Toe-elevating appliance attached to the boot.

(2) Right-angled foot-splint for night wear.

The apparatus shown in the figure is simple and efficient. The steel calf-band is quite loose and does not cause any constriction of the calf, whilst acting as the upper fixed point for the spring. A small metal ring attached to two lace-holes in the boot serves for the lower attachment of the spring. This latter should be strong.

Fig. 121.

Any apparatus taking purchase from the calf, or a felt gaiter, tends to press on the soft parts and cause swelling and discomfort by impeding the venous return.

It is important not to omit the night shoe when a patient is discharged from hospital. The splint should be worn constantly until such time as the patient regains the power of dorsiflexing the foot. The night shoe should be so made as to hold the foot in 10° of dorsiflexion beyond the mid-position.

Patients with foot-drop require frequent examination, as shortening of the tendo Achillis is common, and the splint will not prevent it unless it is correctly applied.

Moreover, in my experience, in a complete lesion of the sciatic, the internal popliteal portion as a rule recovers before the peroneal part, so that the deformity may be produced during a late stage of recovery.

In the rarer cases in which the internal popliteal is injured alone, any tendency to calcaneous deformity can be prevented by a night shoe in slight plantar flexion, and a stop on the boot. There is not, however, the same tendency to deformity here as there is in lesions of the external portion of the nerve.

TREATMENT DIRECTED TOWARDS NUTRITION

Heat. The affected limb should be kept warm at all times, woollen gloves, and in certain cases an extra woollen sleeve in upper limb affections, being used in cold weather.

With incomplete and irritative lesions, heat may cause increased pain, and is then contra-indicated.

Before massage or electrical treatment, the part should always be warmed. Dry heat suffices as a precursor to massage, and may be applied in the form of either radiant heat, diathermy, or the paraffin bath.

The Paraffin Bath. This bath is simply an ordinary receptacle in which paraffin wax is melted and maintained at a temperature of about 130° F. The part to be heated is immersed for ten minutes, and then withdrawn. The thin coating of paraffin wax which covers the part is peeled off and replaced in the bath. The limb is very well heated by this method, which is an admirable precursor to massage.

As a preliminary to electrical stimulation, moist heat is to be preferred to dry heat, for by the thorough soaking of the skin the resistance to the passage of the current is lessened.

No special advantage was found from the use of the *eau-courante* baths in this connexion. The massage or electrical stimulation should immediately follow the heating process.

It is enough to soak the limb in a tub or sink of hot water for five minutes. A limb with a trophic sore should never be soaked or wetted. The sore should be kept dry and clean. The majority of the so-called trophic sores are not really the result of nerve irritation, but rather the effect of trauma on an anæsthetic area. The cigarette burn on the finger with a median lesion, or the ulcer on the sole with a lesion of the internal popliteal nerve, are instances.

Electrical Stimulation. The mere passage of an electric current through the nerve has, in my opinion, no effect upon the regeneration of the axis cylinders, either as regards the rapidity or completeness of the process.

The use of electricity in the after-treatment of peripheral nerve injury

lies in its power of stimulating the paralysed muscles to contract, and so to exercise their function and move the joint in the absence of voluntary power.

There is a constant tendency for muscle, the nerve supply to which has been divided, to undergo complete atrophy. Effective electrical stimulation prevents this process and maintains the muscle in such a state that when the axis cylinder has grown from the proximal end of the nerve, through the line of suture, and down the segment peripheral to the suture, to the muscle, the latter can at once begin to resume its function.

Unless electrical treatment is well done, it may do harm by stimulating only the normal muscles, and so assist in producing contracture. But it is quite simple to do it well. Many writers on this subject, and some neurologists, prefer to rely on massage alone. If the electrical stimulation is correctly done, it must, I think, be of the greatest value, for the contracting muscles produce a true auto-massage of the part. Its effects are especially noticeable in the small muscles, such as the interossei, after an ulnar nerve lesion, in which the wasting can be kept to a minimum.

lectrical treatment should commence as soon as the wounds are healed.

During the early stages a few contractions of each muscle are produced, the amount of work done being gradually increased from day to day as the nutrition of the muscle improves—and it will improve with treatment, long before regeneration of the nerve takes place.

The most convenient electrical apparatus and technique to employ are the following :

A galvanic switchboard actuated from a direct current main, or accumulators, is connected via a reversing metronome to the patient.

The terminals are two insulated knobs about $\frac{3}{4}$ inch in diameter, and these are both applied longitudinally to the paralysed muscle. This bipolar method is better than the unipolar, in which a small active electrode on the muscle, and a large indifferent electrode on some distant part, e. g. the back, is employed, because using the bipolar method the current is more localized to the paralysed muscle, and does not tend so much to overflow and stimulate the non-paralysed groups.

This overflow is a difficulty sometimes met with particularly in the treatment of certain groups, notably the extensors of the wrist and hand. It is largely overcome by using the technique advised.

Attempts to still further limit the action of the current to the paralysed groups have been and are being made.[1]

Each muscle is exercised individually, its tendon plays in its sheath, and the joint on which it exerts traction is moved.

[1] 'The Selective Treatment of Paralysed Muscles,' by W. J. Turrell, M.B. Oxon., *B. M. J.*, June 29, 1918, p. 904.

From time to time the muscle is tested with the faradic current, and as soon as it begins to respond to this form of stimulus, it is treated first with the galvanic and then with the faradic at the same sitting. The muscle will not recover all at once, but as it begins to recover, the response to faradic stimulation more nearly simulates voluntary action, and is to be preferred.

The technique, electrodes, metronomes, &c., are the same, but a faradic coil is in circuit instead of the galvanic switchboard.

With full recovery of faradic excitability the galvanic stimulation is omitted. With recovery of faradic excitability, and immediately the muscle has been treated electrically, the masseuse spends some five minutes in re-education.

Re-education. The method adopted is an attempt to train the patient to reproduce voluntarily the movement which has just been provoked electrically. This is a most important part of the after-treatment, and the rapidity and completeness of the cure depend to a great extent on its being carried out in a systematic and painstaking way.

Re-education must be one of the main principles underlying the after-treatment all through. Re-education is necessary in order that the higher centres which initiate voluntary movement may be kept functioning.

The cortex and higher centres deal with movements, not with muscles, and by an appreciation of what movements are taking place and their range, these centres are re-trained.

Re-education does not consist in teaching the patient to make trick movements, utilizing combinations of normal muscles and paralysed ones, which act as ligaments, for if this is done the paralysed muscles are liable to be stretched, and also bad habits are formed which are difficult to eradicate. As an instance, it is quite possible for a man with complete median and ulnar paralysis to be trained to flex his wrist and partly close his fingers. The first he does by using his extensor ossis metacarpi pollicis, and the second by using his wrist extensors. The wrist being extended and the extensor communis voluntarily inhibited, the paralysed flexors of the fingers function as ligaments and approximate the fingers to the palm. These and other trick movements which have been referred to under 'Diagnosis' are commonly met with.

In the early stages the patient should notice and realize the range of movement at any given joint, but he should not strive to reproduce it until muscle recovery is commencing, as will be generally evidenced by the return of faradic excitability.

Massage. To what extent massage may be replaced by electrical stimulation and the auto-massage so produced is an open question.

In all cases in which there is œdema, massage is essential, and it is essential also when the skin itself is thickened and pathological.

When œdema is present massage should always precede either electrical stimulation or electrical testing.

In other cases it is simply utilized as an additional aid to nutrition, chiefly from its effect on the lymphatic circulation. This effect is largely mechanical, and is best brought about by kneading, all movements being directed from the periphery towards the centre.

The secondary effect of massage lies in its reflex action on the blood-vessels. The reflex effects are induced by light stroking (*effleurage*) which may be directed either towards the centre or towards the periphery. No massage over the site of lesion should be allowed in the early stages, but by loosening of scars, &c., it is of value in the later stages in this situation.

Remedial Exercises and Re-education. As noticed under the paragraph on electrical treatment, the re-education must be commenced and persevered with from the earliest possible moment.

After the nerve has once soundly healed, activity of the affected limb is the dominant factor towards which all after-treatment leads.

It was pointed out to me recently by Dr. Levick that small quick movements would probably be the best form of re-education judging from the analogy of the training of athletes. From the results obtained this seems to be the best method to adopt.

Rapid co-ordination of the smaller and finer movements of the hand is especially necessary. The coarse movements of the big muscles of the thigh or calf need nothing more than general exercises, and recover their co-ordination as they recover their strength. The balancing exercises of the Swedish system seem best suited to them.

But the fine movements, and especially the rapid performance of them, need careful training. Piano-playing, type-writing, and exercising machines modelled on similar lines are all of service, but in the very earliest stages it is the careful attention and encouragement given by the masseuse to the individual movement which most rapidly induces the patient to use the muscles and co-ordinate the movements.

In orthopædic centres, the curative workshops are available and are most valuable at this later stage, provided that the right type of work is ordered and that it is carried out under supervision. The patient will learn to use his hand more quickly and more completely if he employs it daily on some congenial constructive work.

NOTE ON END RESULTS OF NERVE INJURIES

BY

Captain C. BERESFORD ALEXANDER, R.A.M.C. (T.F.)

Alder Hey Special Military Surgical Hospital, West Derby, Liverpool

NOTE ON END RESULTS OF NERVE INJURIES

In the vast field of war surgery no section has claimed so many observers or proved so fascinating and instructive as that which deals with injuries to peripheral nerves.

It is, however, very doubtful whether the store of material available at the present time is being utilized as it should be. Men who in the whole of their surgical experience before this war had sutured perhaps ten or a dozen nerves are now operating on as many in a week. If anything more can be learned about nerve degeneration and regeneration surely now is the time. To this end there should be the closest possible collaboration between surgeon, pathologist, and physiologist. That this collaboration rarely exists is only too obvious to all who try to trace the end results of nerve lesions.

When any pensioner suffering from nerve injury reports at the out-patient department at Alder Hey Special Military Surgical Hospital it has been our practice to write for information to the hospital where he was treated. Only too often the report returned is very meagre, without reference to any pathological findings, or to the condition found at operation, other than 'nerve sutured' or 'nerve freed from scar'.

Quite apart from the question of research the whole of the treatment of nerve injuries is influenced by results obtained, and from one point of view any end result, however perfect or satisfactory to the patient, is wasted unless a full and complete history of the case is available.

The difficulties of tracing cases after discharge from hospital are numerous but not always insurmountable. In the big orthopædic centres there are always out-patient clinics for pensioners, and here in Liverpool, at any rate, a large proportion of those receiving treatment are nerve injuries. In our experience the majority of pensioners living within a radius of fifty miles or so are only too willing to report about every three months for examination and advice from a neurologist, especially if he is attached to the hospital in which they were previously patients. When cases live too far away to report, their local war pensions committees are generally very helpful in causing them to be examined by some competent surgeon at a hospital where they receive their after-treatment or near where they are employed. A good deal of useful information can be obtained by writing a carefully worded letter direct to the patient asking him a number of questions in simple language, e.g.:

In lesions of the median nerve above the elbow.

Can you close your fist?

Can you bend the end joint of your thumb? (*Flexor Longus Pollicis*).

Can you touch the tip of your little finger with the end of your thumb ? (*Opponens Pollicis*), &c.

Although the deductions obtained by this latter method are not nearly so satisfying as an actual examination and only yield information about return of voluntary power and protopathic sensation, nevertheless if replies are received at regular intervals over an extended period the percentage of error is very much smaller than would be thought—as actual examination of about 250 cases previously written to has recently proved.

Such information obtained by letter, however, only helps us to gauge how soon recovery takes place, and does not materially assist us in determining the sequence in which the various signs of recovery occur.

During recent months we have examined a considerable number of cases at intervals varying from one to thirty months after operation. The condition of some of these at their last examination is tabulated at the end of the chapter.

One could enumerate a hundred details which influence recovery after injury to a nerve without consideration of the actual operative technique. Take, for example, the musculo-spiral :

Was the humerus fractured ?

How many months elapsed before the wound healed ?

What was the organism responsible for suppuration ?

Was the nerve secondarily involved in callus ?

How soon after sepsis has subsided was suture performed ?

Were the paralysed muscles relaxed by the use of some suitable orthopædic appliance ?

Did those muscles receive proper pre- and post-operative massage and electrical treatment ?

What was the age of the patient and his general condition ? &c., &c.

All these points and many others have their proper bearing on the prognosis.

All observers agree that different peripheral nerves vary in the time of recovery. It would seem that this difference, quite apart from questions of blood supply and so on, largely depends on two main factors :

(A) The length of time before lesion of the nerve is diagnosed and therefore before it receives treatment, and

(B) The size and function of the muscles supplied by the injured nerve.

The musculo-spiral and external popliteal lesions are generally noticed early in virtue of the fact that they advertise themselves at once. A dropped wrist or foot is immediately recognized and treated by appropriate splinting, while other peripheral nerves, particularly the ulnar and internal popliteal, are frequently missed.

While examining a case of fractured femur recently admitted to Alder Hey we happened to notice that the patient's hand, as it rested on the bed-cover, was markedly wasted, and that the ring and little fingers were slightly contracted. Investigation showed that this man had been wounded before. Over a year previously he had received a small bullet wound just above the elbow that healed in a few days, and six weeks after which he was returned to duty. He had a complete lesion of his ulnar nerve which had been overlooked. That injuries to the ulnar nerve are without doubt frequently missed is shown in another way. Quite a fair proportion of the patients at Alder Hey were derived from two large command dépôts where men were collected for hardening, preparatory to being sent to the front again. Cases selected as unsuitable by M.O.'s in charge of these dépôts were examined from time to time by an orthopædic surgeon. Of the nerve injuries seen under these conditions over 50 per cent. were ulnar.

Factors which influence the prognosis are :

Firstly, the length of suppuration—except in those cases where the wound heals in a few days suture should not be attempted until two months after this has subsided ; and possibly,

Secondly, unnecessary delay before suture is performed.

In our experience of the two conditions the former has a more unfavourable effect on the prognosis than the latter. Compare, for example, Nos. 171 (page 266) and 132 (page 264) shown in Table No. VI. Both these were sutured approximately nine months after injury, but in case No. 132, which is only commencing to recover, the length of time between the date of injury and the healing of the wound was seven months, while in No. 171, which has recovered, this was only four months.

It does not follow, however, that suture should not be performed at the casualty clearing stations whenever possible. This is a sound surgical procedure, and even if the wound later breaks down and restoration of function is thus delayed the surgeon has at least done something if he helps to preserve anatomical relations and, by anchoring the divided ends of the nerve, prevents these from separating. Although this sepsis delays repair it does not necessarily prevent it. We have records of several cases sutured at casualty clearing stations in which voluntary power has returned although the wound when last examined had not healed.

Re-suture of a nerve which is apparently stationary is occasionally justified and has seemed to hasten recovery. Case No. 419 (page 250) can be quoted as an example. This patient's median nerve was first sutured in the ante-cubital fossa twelve months after he was hit, but at the end of nearly a year showed no sign of commencing recovery. Accordingly

we operated again. The nerve was found continuous with a large very hard bulbous swelling in the region of the previous suture, the whole being with difficulty dissected out of very dense scar tissue. As much as possible of the surrounding cicatrix was removed, the bulb excised, a fresh muscle-bed made, and the ends sutured. Recovery commenced at the end of three months and by the fourth month good voluntary power had returned. The pathologist's report (Capt. Cone, M.R.C.) showed that the bulb contained what was practically a curtain of scar tissue dropped across the path of such fibres as were attempting to grow from the proximal end. The distal portion of the nerve contained embryonic nerve tendrils in loose hæmorrhagic connective tissue. Apparently sufficient fibres had reached the peripheral segment to hasten regeneration, conduction of impulses, however, being evidently impeded by scar both in and about the nerve.

Statistics. We have been able to trace by various means over five hundred cases of nerve lesions which have passed through Alder Hey Hospital. Figures shown in Table I are deduced from these and compare very closely with those published by us in the *British Medical Journal*, March 30, 1918.

In compiling Tables II, III, IV, and V we have made no use of cases we have examined other than those which showed complete physiological interruption, i. e. no voluntary power, absence of faradism, and loss of both epicritic and protopathic sensation. They have all been examined by us personally, and do not include any we have traced by means of letter or in any other way. We are indebted to Major Cross (Australian Medical Corps), who has assisted us in presenting the available figures in the form which we think will be the most useful.

TABLE I

Showing relative frequency in which the different peripheral nerves are involved.

	Percentage.
Ulnar	30·33
Median	26·49
Musculo-spiral	15·46
External Popliteal	9·86
Sciatic	6·18
External Half Sciatic	3·28
Posterior Interosseous	2·17
Internal Popliteal	1·93
Posterior Tibial	1·54
Internal Half Sciatic	1·35
Anterior Tibial	0·96
Anterior Crural	0·38

TABLES II, III, AND IV

Analysis of cases of nerve injuries with complete physiological interruption, showing results of last examination (except in case of recovery of voluntary power where the first examination showing such return has been taken).

TABLE II. RESECTION AND SUTURE

Period between injury and operation.		Period in months between suture and last examination. 0–6.	6–12.	12–18.	18–24.	24–36.	*Total.*	
a. 0–6 months	R.	2	11	4	7	1	25	
	P. R.	1	11	2	1	—	15	
	C. R.	2	3	1	—	—	6	
	N. C.	5	2	4	—	—	11	57
b. 6–12 months	R.	6	5	3	—	—	14	
	P. R.	3	2	4	—	—	9	
	C. R.	2	4	—	—	—	6	
	N. C.	6	2	1	1	1	11	40
c. 12–18 months	R.	1	—	—	—	—	1	
	P. R.	2	1	—	—	—	3	
	C. R.	1	1	—	—	—	2	
	N. C.	1	1	—	—	—	2	8
d. 18–24 months	R.	1	1	—	—	—	2	
	P. R.	1	—	2	—	—	3	
	C. R.	2	—	1	—	—	3	
	N. C.	3	—	—	—	—	3	11
							Total	116

TABLE III. NEUROLYSES

Period in months between operation and last examination.

	0–6.	6–12.	12–18.	18–24.	24–36.	*Total.*
R.	13	8	11	—	—	32
P. R.	4	1	1	1	1	8
C. R.	2	—	—	—	1	3
N. C.	—	—	1	2	—	3
						46

TABLE IV. CASES NOT OPERATED UPON

Period in months between injury and last examination.

	0–6.	6–12.	12–18.	18–24.	24–36.	*Total.*
R.	1	1	4	4	5	15
P. R.	—	1	—	—	2	3
C. R.	—	2	—	1	—	3
N. C.	3	1	1	1	—	6
						27

NOTE.—Complete physiological interruption = vol. power nil. Faradism absent. Epicritic and protopathic sensation lost.

R = Recovery = Definite return of voluntary power.

P. R. = Partial recovery = vol. power nil. Protopathic sensation returned.

C. R. = Commencing recovery = Faradism absent. Vol. power nil. Tinel's sign present. N. C. = No change = Still complete physiological interruption.

The terms RECOVERY, PARTIAL RECOVERY, COMMENCING RECOVERY, and NO CHANGE have been chosen not with the idea of indicating the degree of function in the affected limb but rather to show when definite stages have been reached.

As serial observations of individual cases at regular intervals unfortunately were not always possible, each case dealt with appears only once in the above tables either for the first period wherein a return of voluntary power was manifested, or for the period wherein it was last tested and found to show recovery to a less degree or no change. Thus each group of cases is an independent set, has no case in common with any other group, and may be regarded as being more or less a collection of random samples. The tables are, therefore, an analysis of 189 different cases.

The proportion of the total observed recoveries of voluntary power to the total number of cases examined, as shown in the last column of Table II, gives :

For cases sutured within 6 months of injury (group 2 *a*), 25 out of 57=44 per cent.

For cases sutured within 6–12 months of injury (group 2 *b*), 14 out of 40=35 per cent.

It will be observed, however, that in group 2 *a*, a considerably higher proportion of cases were seen in the later post-operative periods than was the case in group 2 *b*, so that presumably the ultimate increase of favourable results over the observed would be greater in the latter group than in the former.

Thus no definite conclusion with regard to proportion of ultimate recoveries in the two groups can be made from the limited number of cases dealt with. They appear to be approximately equal. With regard to the rate of recovery, the proportion of cases showing return of voluntary power within 6 months of operation is :

For cases operated on within 6 months of injury 2 out of 10, or 20 per cent.
,, ,, ,, 6–12 ,, 6 out of 17, or 35 per cent.

indicating a possibly more rapid recovery in the latter cases. The available number of observations is too small to allow of much weight being attributed to these findings. They should, however, be recorded so as to be available for combination with other series of similar observations.

With regard to **neurolyses** (Table III), cases in which this procedure was considered sufficient show a high proportion, at least 70 per cent. of favourable results, as measured by return of voluntary power. Here again several cases not showing such return have only been seen within six months of operation.

TABLE V

Showing results up to last examination of suture of ulnar, median, and the musculo-spiral nerves, all of which before operation had complete physiological interruption.

		3–6.	6–12.	12–18.	18–24.	*Total.*	
		Period in months between operation and last examination.					
Ulnar	R.	2	5	5	3	15	
	P. R.	—	3	1	—	4	
	C. R.	1	5	2	1	9	
	N. C.	10	3	3	—	16	44
Median	R.	3	2	—	2	7	
	P. R.	5	2	—	—	7	
	C. R.	2	1	—	—	3	
	N. C.	5	—	1	—	6	23
Musculo-spiral	R.	1	6	2	3	12	
	P. R.	1	—	—	—	1	
	C. R.	1	1	2	—	4	
	N. C.	2	—	—	2	4	21

The proportions of observed recoveries for nerves of the upper limb are therefore as follows:

Ulnar	15 recoveries out of	44 = 34	per cent.
Median . . .	7 ,, ,,	23 = 30	,,
Musculo-spiral . .	12 ,, ,,	21 = 57	,,

Of cases, however, seen later than six months after operation, the proportion of observed recoveries is:

Ulnar	13 recoveries out of	31 = 42	per cent.
Median . . .	4 ,, ,,	8 = 50	,,
Musculo-spiral . .	11 ,, ,,	16 = 69	,,

which probably gives a truer indication than the results obtained from Table V as a whole.

Tables VI and VII, which follow, comprise 100 cases of suture and 100 cases of neurolysis examined recently, and show the condition before operation and at last examination. They were not in every instance cases of complete physiological interruption but were selected at random. We should again point out that in Table VI, as in Tables II, III, IV, and V, the terms 'Recovery', 'Partial Recovery', 'Commencing Recovery', and 'No Change', do not refer to the degree of function in the affected limb, but indicate that certain definite stages on the road to recovery have or have not been reached. In Table VII, however, the terms used in the column showing the resulting condition are meant to indicate the result of the operation up to the time of the last examination.

In the column headed 'Number of Months after Operation before Recovery Commenced' the prefix letter 'V' indicates voluntary, and 'P' protopathic return.

F+, or A = Faradism present or absent.

G+, or A = Galvanism present or absent.

E = Epicritic sensation.

P = Protopathic sensation.

TABLE VI.—

Serial No.	Name.	No. of months between injury and healing of wound.	No. of months between healing of wound and operation.	No. of months between operation and last examination.	Electrical re-actions before operation.	Electrical re-actions at last examination.	Sensory loss before operation.	Signs of sensory recovery at last examination.
434.	A.D.	3.	5.	2.	F. fair.	F. good.	E & P.	Nil.
		Operation suture performed to relieve pain.						
430.	W.A.C.	1.	1.	2.	F.A.	F.A. G.+	E & P.	Nil.
8.	J.R.	1.	10.	2.	F.A. G.A.	F.A.	E & P. lost.	Nil.
411.	G.G.	9.	4.	3.	F.A.	F.A. G.+	E & P.	Nil.
412.	R.M.	2.	4.	3.	F.A.	F.A. G.+	E & P.	Nil.
34.	T.R.	7.	11.	3.	F.A.	F.A.	E & P.	Nil.
62.	C.M.	20.	1.	3.	F.A. G.A.	F.A. G.+	E & P.	Nil.
431.	A.M.	2.	1.	3.	F.A. Abd. Poll. F.+ Opp. Poll.	F.A. Abd. Poll. F.+ Opp. Poll.	E & P.	Nil.
18.	H.H.	5.	17.	4.	F.A. G.A.	F.A. G.+ except supinator long.	E & P.	E & P. both returned.
28.	E.H.	2.	7.	4.	F.A.	F.A. G.+	E & P.	Protopathic commencing to return.
106.	P.A.J.	8.	6.	4.	F.A. G.+	F.A. G.+	E & P.	Nil.
419.	F.R.C.	1.	12. Re-suture 22	Suture 13. Re-suture 4.	F.A.	F.+	E & P.	Nil.

SUTURES.

Vol. power in muscles below lesion before operation.	*Vol. power in muscles below lesion at last examination.*	*No. of months after operation before recovery commenced.*	*Other signs of recovery.*	*Resulting condition.*	*Site of injury.*	*Nerve involved.*
Slight.	+	V. 2 mths.	No pain except tingling pain on percussion below site of injury referred to median area.	Recovery.	Lower third forearm.	Median.
Nil.	Nil.		Tingling pain on percussion over radial nerve middle third forearm.	Commencing recovery.	Middle third arm.	Musculo-spiral.
Nil.	Nil.			No change	Wrist.	Ulnar.
Nil.	Nil.		Increase in girth of leg.	No change.	Buttock.	Sciatic.
Nil.	Nil.			No change.	Knee.	External popliteal.
Nil.	Nil.		Percussion over nerve middle of forearm, tingling pain ulnar area.	Commencing recovery.	Lower third arm.	Ulnar.
Nil.	Nil.			No change.	Upper third leg.	External popliteal.
Nil.	Fair.			Recovery.	Lower third forearm.	Median.
Nil.	Nil except supinator longus and extensor com. slight.	V. 4 mths.		Recovery.	Upper third arm.	Musculo-spiral.
Nil.	+		Percussion over nerve lower third forearm, tingling pain over median area.	Recovery.	Elbow.	Median.
Nil.	Nil.			No change.	Middle third leg.	Posterior tibial.
Nil.	+	V. 3 mths. after re-suture.	Percussion over median nerve lower third forearm, tingling pain referred to median area.	Recovery.	Elbow.	Median.

TABLE VI.—

Serial No.	*Name.*	*No. of months between injury and healing of wound.*	*No. of months between healing of wound and operation.*	*No. of months between operation and last examination.*	*Electrical re-actions before operation.*	*Electrical re-actions at last examination.*	*Sensory loss before operation.*	*Signs of sensory recovery at last examination.*
36.	G.W.S.	15.	4.	4.	F.A.	F.A. G.+	E & P.	Nil.
446.	J.A.	Nerve sutured at C.C.S. day of wound.		4.		F.+ Tib. ant. and Peronei others F.A.		Protopathic returned.
91.	G.E.W.	5.	4.	4.	F.A.	F.A.	E & P.	Nil.
91.	G.E.W.	5.	6.	2.	F.A.	F.A.	E & P.	Nil.
232.	F.H.	3.	6.	4.	F.A. G.+	F.A. G.+	E & P.	Nil.
178.	H.P.	1.	6.	5.	F.A. G.+	F.A. G.A.	E & P.	Nil.
164.	A.E.T.	1.	5.	5.	F.A.	F.A.	E & P.	Nil.
83.	F.W.	3.	2.	5.	F.A. G. fair	Flexor sub Opp. Poll. F.+. Remainder F.A.	E & P.	Nil.
354.	C.E.	7.	1.	5.	F.A. G.+	F.+	E & P.	Protopathic returned.
355	P.J.R.	3.	3.	5.	F.A. G.A.	F.A. G.A.	E & P.	Nil.

SUTURES (*continued*).

Vol. power in muscles below lesion before operation.	*Vol. power in muscles below lesion at last examination.*	*No. of months after operation before recovery commenced.*	*Other signs of recovery.*	*Resulting condition.*	*Site of injury.*	*Nerve involved.*
Nil.	Nil.			No change.	Lower third arm.	Musculo-spiral.
	Nil.	P. 3 mths.	Percussion over course of nerve down to ankle, tingling pain referred to anterior tibial area.	Partial recovery.	Knee.	External popliteal.
Nil.	Nil.		Tingling pain on percussion over ulnar nerve at junction lower and middle thirds forearm.	Commencing recovery.	Lower third arm.	Ulnar.
Nil.	Nil.			No change.	Elbow.	Posterior interosseous.
Nil.	Nil.		Tingling pain referred to ulnar area on percussion over nerve at wrist.	Commencing recovery.	Middle third arm.	Ulnar.
Nil.	Nil.		Tingling pain on percussion over nerve at knee; girth of leg has increased.	Commencing recovery.	Middle third thigh.	External half of sciatic.
Nil.	Nil.			No change.	Middle third forearm.	Ulnar.
Nil.	Palmaris longus, Flexor sub. good. Opponens fair. F.L.P. nil. Flexor prof. nil.	V. 4 mths.	Tingling pain on percussion down to lower third forearm referred to median area.	Recovery.	Upper third arm.	Median.
Nil.	Nil.	F. 4 mths.		Partial recovery.	Lower third forearm.	Ulnar.
Nil.	Nil.			No change.	Lower third arm.	Median.

TABLE VI.—

Serial No.	Name.	No. of months between injury and healing of wound.	No. of months between healing of wound and operation.	No. of months between operation and last examination.	Electrical re-actions before operation.	Electrical re-actions at last examination.	Sensory loss before operation.	Signs of sensory recovery at last examination.
355.	P.J.R.	3.	3.	5.	F.A. G.A.	F.A. G.A.	E & P.	Nil.
370.	R.H.	6.	1.	5.	F.A.	F.+	E & P.	Protopathic returned.
421.	J.F.W.	3.	5.	5.	F.A. G.+	F.A.	E & P.	Nil.
421.	J.F.W.	3.	5.	5.	F.A. G.+	F.A.	E & P.	Nil.
426.	L.L.	4.	4.	5.	F.A. G.+ opponens F. fair.	F.L.P. F. slight ab. pol. F. fair op. pol. F. good.	E & P.	Nil.
425.	G.S.	14.	5.	5.	F.A.	F.A.	E & P.	Protopathic returned.
424.	H.McK.	1.	8.	5.	F.A.	F.A.	E & P.	Nil.
56.	M.I.	1.	23.	5.	F.A. G.+	F.A. G. faint.	E & P.	Nil.
38.	W.S.	3.	6.	5.	F.A. G.A.	F.A. G.+	E & P.	Nil.

SUTURES (*continued*).

Vol. power in muscles below lesion before operation.	*Vol. power in muscles below lesion at last examination.*	*No. of months after operation before recovery commenced.*	*Other signs of recovery.*	*Resulting condition.*	*Site of injury.*	*Nerve involved.*
Nil.	Nil.			No change.	Lower third arm.	Ulnar.
Nil.	Slight.			Recovery.	Lower third forearm.	Ulnar.
Nil.	Nil.		Tingling pain on percussion over median nerve well below wound referred to median area.	Commencing recovery.	Lower third forearm.	Median.
Nil.	Nil.		Tingling pain on percussion over ulnar nerve well below wound referred to ulnar area.	Commencing recovery.	Lower third forearm.	Ulnar.
Nil.	Good.		Tinel's sign negative.	Recovery.	Lower third forearm.	Median.
Nil.	Nil.			Partial recovery.	Middle third forearm.	Median.
Nil.	Nil.			No change.	Upper third thigh and buttock.	Anterior crural.
Nil.	Nil.		Percussion over nerve at wrist, tingling pain referred to ulnar area.	Commencing recovery.	Middle third forearm.	Ulnar.
Nil.	Flex. sub. dig.+ Flex. long pol. slight. Flex. profound fair.		Percussion over median nerve middle of forearm, tingling pain referred to median area.	Recovery.	Lower third arm.	Median.

TABLE VI.—

Serial No.	Name.	No. of months between injury and healing of wound.	No. of months between healing of wound and operation.	No. of months between operation and last examination.	Electrical re-actions before operation.	Electrical re-actions at last examination.	Sensory loss before operation.	Signs of sensory recovery at last examination.
422.	S.B.	3.	5.	5.	F.A.	F.A.	E & P.	Nil.
5.	J.L.	2.	4.	5.	F.A.	F.A.	E & P.	Protopathic returning.
186.	M.M.	2.	5.	6.	F.A.	F.+	E & P.	Nil.
367.	A.B.	1.	7.	6.	F.A.	F.+ long median muscles F.A. abd. and opp. pollicis.	E & P.	Protopathic returned.
103.	W.E.F.	10.	5.	6.	F.A. G. fair.	F.A. G. fair.	E & P.	Nil.
374.	V.P.W.	4.	1.	6.	F.A. G.+	F.A. G.+	E & P.	Nil.
149.	R.P.	1.	10.	6.	F.A.	F.+ except flexor longus pollicus.	E & P.	Nil.
139.	J.P.S.	2.	5.	6.	F.A. G.A.	F.A. G.+	E & P.	Nil.
204.	J.R.M.	3.	4.	6.	F.A. G. fair.	F.+	E & P.	Nil.
118.	B.D.	8.	1.	7.	F.A.	F.A. G.+	E & P.	Nil.

SUTURES (*continued*).

Vol. power in muscles below lesion before operation.	*Vol. power in muscles below lesion at last examination.*	*No. of months after operation before recovery commenced.*	*Other signs of recovery.*	*Resulting condition.*	*Site of injury.*	*Nerve involved.*
Nil.	Nil.		Percussion over nerve junction of upper and middle thirds forearm, tingling pain over ulnar area.	Commencing recovery.	Upper third arm.	Ulnar.
? Slight in opponens.	Opponens fair abductor nil.			Partial recovery.	Lower third forearm.	Median.
Nil.	+			Recovery.	Middle third forearm.	Median.
Nil.	Fair.	P. 5 mths.		Recovery.	Upper third arm.	Median.
Nil.	+ except extensors of thumb.			Recovery.	Lower third arm.	Musculo-spiral.
Nil.	Nil.		Tingling pain on percussion below scar referred to ulnar area.	Commencing recovery.	Elbow.	Ulnar.
Nil.	Slight except in F.L.P. nil.		Radiating pain (tingling) on percussion over nerve at wrist.	Recovery.	Lower third arm.	Median.
Nil.	Nil.			No change.	Middle third forearm.	Median.
Nil	Good.		Percussion over nerve at elbow, tingling pain over ulnar area.	Recovery.	Axilla.	Ulnar.
Nil	Nil.		Tingling pain referred to ulnar area on percussion over nerve at wrist.	Commencing recovery.	Left shoulder.	Ulnar.

TABLE VI.—

Serial No.	Name.	No. of months between injury and healing of wound.	No. of months between healing of wound and operation.	No. of months between operation and last examination.	Electrical re-actions before operation.	Electrical re-actions at last examination.	Sensory loss before operation.	Signs of sensory recovery at last examination.
118.	B.D.	8.	1.	7.	F.A.	F.A. G.+	E & P.	E & P. returning.
190.	S.M.	2.	1.	7.	F.A.	F.A.	E & P.	Nil.
338.	F.B.	1.	3.	7.	F.A.	F.+ in all.	E & P.	Protopathic commencing to return over hypo-thenar eminence.
350.	F.H.	5.	10.	7.	F.A.	F.+	E & P.	Nil.
350.	F.H.	5.	10.	7.	F.A.	F.A.	E.& P.	Nil.
357.	B.F.	1.	4.	7.	F.A.	F.A. G.+	E & P.	Protopathic returned.
423.	C.P.	2.	3.	7.	F.A.	F.A.	E & P.	Nil.
428.	C.W.C.	9.	2.	7.	F.A. G.A.	F.A. G.A.	E & P.	Nil.
20.	P.M.C.	6.	3.	8.	F. A. in all.	F.A. in all.	E & P.	Nil.

SUTURES (*continued*).

Vol. power in muscles below lesion before operation.	*Vol. power in muscles below lesion at last examination.*	*No. of months after operation before recovery commenced.*	*Other signs of recovery.*	*Resulting condition.*	*Site of injury.*	*Nerve involved.*
Nil.	Flex. sub. slight, Flex. long. poll. slight, others nil.		Tingling pain referred to median area on percussion over nerve above wrist.	Recovery.	Left shoulder.	Median.
Nil.	Nil.		Percussion over int. and ext. pop. nerves at knee causes tingling pain over their distribution. Leg much fatter.	Commencing recovery.	Upper third thigh.	Sciatic.
Nil.	+		Only slight wasting now.	Recovery.	Lower third forearm.	Ulnar.
Nil.	Slight.			Recovery.	Lower third forearm.	Median.
Nil.	Nil.			No change.	Lower third forearm.	Ulnar.
Nil.	Nil.	P. 5 mths.		Partial recovery.	Upper third arm.	Musculo-spiral.
Nil.	Nil.		Percussion over ulnar nerve middle forearm, tingling pain ulnar area.	Commencing recovery.	Middle third arm.	Ulnar.
Nil.	Nil.		Percussion over both nerves at knee, tingling pain referred to both areas.	Commencing recovery.	Middle third thigh.	Sciatic.
Nil in all.	Nil in all.		When skin is pinched over musc. cut. area pain is tingling in character. Tinel's sign+ for int. and ext. pop. at knee.	Commencing recovery.	Buttock.	Sciatic.

TABLE VI.—

Serial No.	*Name.*	*No. of months between injury and healing of wound.*	*No. of months between healing of wound and operation.*	*No. of months between operation and last examination.*	*Electrical re-actions before operation.*	*Electrical re-actions at last examination.*	*Sensory loss before operation.*	*Signs of sensory recovery at last examination.*
371.	W.J.C.	3.	4.	8.	F.A.	F.A. G.+	E & P.	Protopathic commencing to return.
131.	A.S.	3.	3.	8.	F.A.	F.+ flexor carpi ulnaris, others F.A.	E & P.	Protopathic returned over hypo-thenar eminence.
409.	T.D.	7.	10.	8.	F.A.	F.A. G. faint.	E & P.	Protopathic returned.
236.	F.F.	1.	4.	9.	F.A. G.+	F.C.U. F.+ remainder F.A.	E & P.	Protopathic returning over ulnar area.
318.	J.S.	3.	4.	9.	F.A. G.+	F.+	E & P.	Protopathic returned.
406.	J.F.	2.	2.	9.	F.A.	F.C.U. F.+ others F.A. G.A.	E & P.	Protopathic returning.
351.	W.M.S.	2.	2.	9.	F.A.	F.A. G.+	E & P.	Nil.
360.	W.E.	6.	4.	9.	F.A.	F.A. G.+	E & P.	Protopathic returned.
429.	J.I.B.	1.	1.	10.	F.A.	F.+	E & P.	Protopathic returned.
64.	N.F.	Nerve sutured at C.C.S. a few days after wound.		10.		Tib. ant. F.+ others F.A. G.A.		Protopathic present over musc. cut. area.
378.	F.O.	4.	3.	10.	F.A. G.+	F.A. G.+	E & P.	Protopathic returned.

SUTURES (*continued*).

Vol. power in muscles below lesion before operation.	*Vol. power in muscles below lesion at last examination.*	*No. of months after operation before recovery commenced.*	*Other signs of recovery.*	*Resulting condition.*	*Site of injury.*	*Nerve involved.*
Nil.	Nil.			Partial recovery.	Upper third thigh.	External half sciatic.
Nil.	+ Flexor carpi ulnaris, others nil.			Recovery.	Shoulder.	Ulnar.
Nil.	Nil.		Tingling pain referred to ulnar area on percussion over nerve at wrist.	Partial recovery.	Middle third forearm.	Ulnar.
Nil.	Nil except flexor carpi ulnaris (slight)		Tingling pain referred to ulnar area on percussion over nerve at wrist.	Partial recovery.	Upper third arm.	Ulnar.
Nil.	+			Recovery.	Upper third arm.	Ulnar.
Nil.	Flexor carpi ulnaris +, others nil.	P. 7 mths.		Recovery.	Lower third arm.	Ulnar.
Nil.	Good.		Tingling pain on percussion over course of nerve below wound referred to radial area.	Recovery.	Lower third arm.	Musculo-spiral.
Nil.	Nil.			Partial recovery.	Middle third forearm.	Ulnar.
Nil.	Good.			Recovery.	Junction upper and middle thirds forearm.	Ulnar.
	Tib. anticus vol. slight, others nil.	P. 6 mths.		Partial recovery.	Knee.	External popliteal.
Nil.	Nil.	P. 9 mths.	Extensor surface of forearm fattening.	Partial recovery.	Upper third arm.	Musculo-spiral.

TABLE VI.—

Serial No.	Name.	No. of months between injury and healing of wound.	No. of months between healing of wound and operation.	No. of months between operation and last examination.	Electrical re-actions before operation.	Electrical re-actions at last examination.	Sensory loss before operation.	Signs of sensory recovery at last examination.
194.	G.P.	1.	5.	10.	F.A. G.+	F.A. G.+	E & P.	Protopathic returning.
122.	J.A.	4.	2.	10.	F.A. G. faint.	F.+	E & P.	Commencing protopathic return.
122.	J.A.	4.	2.	10.	F.A. G. faint.	F.+	E & P.	Protopathic returned.
192.	E.G.	4.	10.	11.	F.A. G.+	F.+	E & P.	Epicritic returned over greatest part of median area, P. returned.
294.	C.C.	2.	3.	11.	F.A.	F.A.	E & P.	Protopathic returned.
197.	J.F.K.	2.	1.	11.	F.A.	F.+	E & P.	E & P. returned everywhere except sole, where E. only is lost.
206.	R.T.G.	7.	5.	11.	F.A.	F.+	E & P.	
365.	S.H.	2.	1.	12.	F.A.	F.+	E & P.	Nil.
105.	H.P.	1.	1.	12.	F.A.	F.+ in all.	E & P.	Protopathic returned.
191.	J.H.J.	2.	1.	13.	F.A.	F.A. G.+	E & P.	Protopathic returning.
217.	R.H.S.	3.	9.	13.	F.A.	F.A.	E & P.	Protopathic returned.
215.	F.S.	2.	8.	13.	F.A.	F. slight.	E & P.	Protopathic returned.

SUTURES (*continued*).

Vol. power in muscles below lesion before operation.	*Vol. power in muscles below lesion at last examination.*	*No. of months after operation before recovery commenced.*	*Other signs of recovery.*	*Resulting condition.*	*Site of injury.*	*Nerve involved.*
Nil.	Good.	V. 4 mths.		Recovery.	Elbow.	Posterior interosseous.
Nil.	Abduct. min. dig. +, interossei A.			Recovery.	Wrist.	Ulnar.
Nil.	+			Recovery.	Wrist.	Median.
Nil.	Nil.			Partial recovery.	Lower third forearm.	Median.
Nil.	Extensors of thumb returned, extensor communis no return.			Recovery.	Elbow.	Posterior interosseous.
Nil.	Fair.			Recovery.	Upper third thigh.	Sciatic.
Nil.	Good in all except extensor communis.			Recovery.	Middle third arm.	Musculo-spiral.
Nil.	Fair extensors of wrist, slight in extensors of thumb.		Tingling pain on percussion over nerve well below scar referred to radial area.	Recovery.	Lower third arm.	Musculo-spiral.
Nil.	+ all muscles except interossei.	P. 11 mths. V. 9 mths.	Tingling pain on percussion over nerve in forearm referred to ulnar area.	Recovery.	Elbow.	Ulnar.
Nil.	Nil except slight in tibialis ant.			Recovery.	Middle third thigh.	Ext. half of sciatic nerve.
Nil.	Nil.			Partial recovery.	Upper third arm.	Musculo-spiral.
Nil.	Slight.			Recovery.	Lower third forearm.	Ulnar.

TABLE VI.—

Serial No.	*Name.*	*No. of months between injury and healing of wound.*	*No. of months between healing of wound and operation.*	*No. of months between operation and last examination.*	*Electrical re-actions before operation.*	*Electrical re-actions at last examination.*	*Sensory loss before operation.*	*Signs of sensory recovery at last examination.*
372.	J.S.G.	3.	4.	14.	F.A.	F.A.	E & P.	Protopathic returning.
183.	T.H.	4.	1.	14.	F.A. G.A.	F.+	E & P.	Protopathic returned.
162.	M.B.	4.	3.	14.	F.A. G.+	F.C.U. F.+ others F.A.	E & P.	Protopathic returned.
188.	W.E.R.	5.	4.	14.	F.A. G.+	F.+ except peroneus longus.	E & P.	Nil.
170.	G.A.	7.	19.	15.	F.A.	F.A. G.A.	E & P.	Protopathic completely returned.
402.	J.J.B.	3.		15.	N.A.	F.A. G.+	E & P.	Nil.
		Sutured at C.C.S.						
147.	A.S.	8.	1.	16.	F.A.	F.A. except abductor hallucis F.+	E & P.	Protopathic returned.
132.	M.W.	7.	2.	17.	F.A.	F.A. G.+	E & P.	Protopathic returning.
389.	R.W.	3.	5.	17.	F.A.	F.A. G.+	E & P.	Nil.
150.	J.L.	2.	5.	17.	F.A.	F.+	E & P.	Protopathic commencing to return.
315.	J.S.H.	2.	3.	18.	F.A. G.A.	F.A. G.A.	E & P.	Nil.
315.	J.S.H.	2.	3.	18.	F.A. G.A.	F.A. G.A.	E & P.	Nil.

SUTURES (*continued*).

Vol. power in muscles below lesion before operation.	*Vol. power in muscles below lesion at last examination.*	*No. of months after operation before recovery commenced.*	*Other signs of recovery.*	*Resulting condition.*	*Site of injury.*	*Nerve involved.*
Nil.	Slight int. pop.	V. 12 mths.		Recovery, internal half; partial, external half.	Upper third thigh.	Sciatic.
Nil.	+	P. 4 mths. V. 13 mths.	Hand filling out.	Recovery.	Wrist.	Ulnar.
Nil.	F.C.U. +, others nil.			Partial recovery.	Elbow.	Ulnar.
Nil.	Nil.	First faradic response 14 mths.		Partial recovery.	Upper third leg.	External popliteal.
Nil.	Nil.	P. 6 mths.		Partial recovery.	Knee.	External popliteal.
	Nil.			No change.	Middle third forearm.	Ulnar.
Nil.	+ except abductor hallucis.	P. 12 mths.		Recovery.	Middle third leg.	Posterior tibial.
Nil.	Nil.		Tingling pain on percussion over nerve below knee referred to ant. tibial area.	Partial recovery.	Lower third thigh.	External popliteal.
Nil.	Nil.		Tingling pain referred to musc. cut. and ant. tibial areas on percussion over ext. pop. at knee.	Commencing recovery.	Upper third thigh.	External half of sciatic.
Nil.	+ in all.			Recovery.	Lower third arm.	Ulnar.
Nil.	Nil.			No change.	Middle third arm.	Ulnar.
Nil.	Nil.			No change.	Middle third arm.	Median.

TABLE VI.—

Serial No.	Name.	No. of months between injury and healing of wound.	No. of months between healing of wound and operation.	No. of months between operation and last examination.	Electrical re-actions before operation.	Electrical re-actions at last examination.	Sensory loss before operation.	Signs of sensory recovery at last examination.
171.	M.P.	4.	5.	18.	F.A.	F.+	E & P.	Nil.
134.	M.P.	1.	5.	19.	F.A.	F.+ int. pop. muscles, F.A. ext. pop. muscles.	E & P.	Protopathic returned in every area.
405.	V.W.	4.	1.	19.	F.A. G.+	F.A. G.+	E & P.	Protopathic returning.
166.	J.M.	1.	4.	21.	F.A. G.+	F.+	E & P.	Protopathic returned.
179.	E.V.	1	1.	21.	F.A.	F.A. G.+	E & P.	Nil.
129.	E.L.C.	2.	4.	22.	F.A. G.+	F.+ in all except interossei.	E & P.	Protopathic returned.
129.	E.L.C.	2.	4.	22.	F.A. G.+	F.+	E & P.	E. returned over distal phalanx of thumb. P. fully returned.
413.	J.S.	8.	1.	22.	F.A.	F.+	E & P.	Epicritic returning, protopathic returned.
388.	W.M.M.	2.	1.	23.	F.A.	F.+	E & P.	Protopathic return hypothenar eminence.
224.	M.W.	8.	2.	24.	F.A.	F.A. G.A.	E & P.	Nil.
392.	H.F.	3.	1.	24.	F.A.	F.A. G.+	E & P.	Nil.
407.	W.D.	3.	12.	24.	F.A.	F. slight.	E & P.	Nil.

SUTURES (*continued*).

Vol. power in muscles below lesion before operation.	*Vol. power in muscles below lesion at last examination.*	*No. of months after operation before recovery commenced.*	*Other signs of recovery.*	*Resulting condition.*	*Site of injury.*	*Nerve involved.*
Nil.	Slight.			Recovery.	Knee.	External popliteal.
Nil.	Int. pop. good, ext. pop. nil.			*Ext. popliteal*, partial recovery. *Int. popliteal*, recovery.	Buttock.	Sciatic.
Nil.	Nil.	P. 7 mths.		Partial recovery.	Elbow.	Ulnar.
Nil.	Good.	V. 13 mths.		Recovery.	Middle third thigh.	External popliteal.
Nil.	Nil.		Tingling pain referred to radial area on percussion over nerve at elbow.	Commencing recovery.	Upper third arm.	Musculo-spiral.
Nil.	+ except dorsal interossei. In palmar interossei only fair.	P. 12 mths.	Absence of any stiffness in joints.	Recovery.	Middle third arm.	Ulnar.
Nil.	+	V. 11 mths.	Absence of wasting.	Recovery.	Middle third arm.	Median.
Nil	+			Recovery.	Elbow.	Median.
Nil.	Slight.	P. 13 mths.	Hand filling out.	Recovery.	Upper third forearm.	Ulnar.
Nil.	Nil.			No change.	Middle third arm.	Musculo-spiral.
Nil.	+	V. 23 mths.	Only slight wasting ext. muscles forearm.	Recovery.	Lower third arm.	Musculo-spiral.
Nil.	Good in all ext. pop. muscles.	V. 14 mths.		Recovery.	Lower third thigh.	External popliteal.

TABLE VI.—

Serial No.	*Name.*	*No. of months between injury and healing of wound.*	*No. of months between healing of wound and operation.*	*No. of months between operation and last examination.*	*Electrical re-actions before operation.*	*Electrical re-actions at last examination.*	*Sensory loss before operation.*	*Signs of sensory recovery at last examination.*
427.	L.T.	1.	2.	24.	F.A.	F.+	E & P.	E & P. returned over lower ext. cut. musc. spiral. P. returned over radial area.
165.	T.A.	3.	6.	27.	F.A.	F.+ in all.	E & P.	Nil.
		Ulna was transplanted into Median.						
383.	H.R.	2.	1.	28.	F.A.	F.+	E & P.	Protopathic returned.

TABLE VII.—

349.	K.L.	1.	2.	1.	F. feeble.	F.+	E & P.	Protopathic returned.
15.	S.H.	6.	4.	1.	F.+ abd. br. poll. F.A. G.A.	F. slight in all except abd. poll. F.A.	E only.	E & P. lost
447.	J.C.	2.	2.	1.	F.A. G. faint.	F.A. G.+	E & P.	Nil.
458.	J.F.	3.	2.	1.	F.A. except flex. carpi. rad.	F.A. except palm. long and flexor carpi rad.	No loss.	N.A.
458.	J.F.	3.	2.	1.	F.A. G. faint.	F.A. except F.C.U., F. +	E & P. 2½ fingers.	Nil.
489.	P.E.	1.	6.	1.	F.A. except flex. sub. and flex. prof.	F. + except poll. and flex. prof.	No loss.	Nil.
481.	W.F.S.	2.	12.	1.	Int. pop. F.A. ext. pop. F. faint.	Int. pop. F.A. all ext. pop F. faint all.	E & P.	P. returned, E. returning *Ext. pop. area.* P. only returned int. pop.

SUTURES (*continued*).

Vol. power in muscles below lesion before operation.	*Vol. power in muscles below lesion at last examination.*	*No. of months after operation before recovery commenced.*	*Other signs of recovery.*	*Resulting condition.*	*Site of injury.*	*Nerve involved.*
Nil.	+			Recovery.	Lower third arm.	Musculo-spiral.
Nil.	Nil.		Deep sensation has returned.	Partial recovery.	Middle third forearm.	Ulnar.
Nil.	Fair.		Deep sensation completely returned.	Recovery.	Lower third forearm.	Ulnar.

NEUROLYSES.

Nil.	+ in all.			Recovery.	Upper third arm.	Musculo-spiral.
Nil.	Slight except abd. poll. fair.		F. and vol. Power good in opp. pollicis. This is probably supplied by ulnar.	Improvement.	Junction middle and upper thirds forearm.	Median.
Nil.	Slight interossei, others nil.			Improvement.	Middle third forearm.	Ulnar.
+ except opp. pol. abd. poll. and F.L.P.	+ except opp. and abd. poll. and F.L.P.			No change.	Shoulder.	Median.
Nil.	Nil.			No change.	Shoulder.	Ulnar.
Fair.	Good.		Percussion over nerve at wrist, tingling pain referred to median area.	Recovery.	Upper third arm.	Median.
Ext. pop. slight. *Int. pop.* nil.	*Ext. pop.* fair. Int. pop. nil except gastroc. and tib. post.			Improvement.	Buttock.	Sciatic.

TABLE VII.—

Serial No.	*Name.*	*No. of months between injury and healing of wound.*	*No. of months between healing of wound and operation.*	*No. of months between operation and last examination.*	*Electrical re-actions before operation.*	*Electrical re-actions at last examination.*	*Sensory loss before operation.*	*Signs of sensory recovery at last examination.*
478.	E.J.A.	2.	1.	2.	F.+	F.+	E & P.	Nil.
125.	H.B.	2.	3.	2.	F.A. G.+	F.+ except ext. of thumb G.+ F.A.	E & P.	Nil.
286.	H.T.R.	2.	1.	2.	F.A. G. fair.	F.A. except tib. ant. F.+ G.+ in all.	E & P.	Nil.
361.	H.W.	1.	9.	2.	F.A.	F.+	E only.	Nil.
416.	T.E.P.	1.	2.	2.	F.A.	F.A. G.+	E & P.	Nil
8.	J.R.	1.	10.	2.	F.A. G.A.	F.+	E & P.	Protopathic returning.
420.	W.C.M.	3.	7.	3.	F.A. G. faint.	F.A.	E & P. lost over ulnar area.	Protopathic returning.
420.	W.C.M.	3.	7.	3.	F.A. G. faint.	F.+ all except abd. and opp. poll. F.A.	E only lost.	Nil.
420.	W.C.M.	3.	7.	3.	F.A. G. faint.	F.+ except extensors of thumb F.A.	E only lost.	Nil.
95.	J.C.	2.	6.	3.	F.A. except flexors of forearm.	F.+ except flexor profundus and abd. poll.	E & P.	Protopathic returned.
448.	W.J.	2.	6.	3.	F.C.U. F.A. G.+ others F. faint.	F.+ in all.	E & P.	Nil.

NEUROLYSES (*continued*).

Vol. power in muscles below lesion before operation.	*Vol. power in muscles below lesion at last examination.*	*No. of months after operation before recovery commenced.*	*Other signs of recovery.*	*Resulting condition.*	*Site of injury.*	*Nerve involved.*
Fair.	Fair.			No change.	Lower third forearm.	Median.
Nil.	+ in all.	V. 2 mths.		Recovery.	Upper third arm.	Musculo-spiral.
Nil.	+ except peroneus longus.		Percussion over nerve 4 inches below wound, tingling pain referred to musc. cut. and ant. tib. areas.	Recovery.	Knee.	External popliteal.
Nil	Nil.			Improvement.	Lower third forearm.	Ulnar.
Nil.	Nil.			No change.	Lower third arm.	Musculo-spiral.
Slight.	Good.			Recovery.	Wrist.	Median.
Nil.	Nil.		Tingling pain on percussion over nerve at elbow referred to ulnar area.	Slight improvement.	Shoulder.	Ulnar.
Nil.	+ except abd. and opp. poll. A.			Improvement.	Shoulder.	Median.
Nil.	+ in all.			Recovery.	Shoulder.	Musculo-spiral.
Nil.	Good.			Recovery.	Upper third. forearm.	Median.
Fair except adductors of fingers slight.	+ in all.		Percussion over nerve mid forearm, tingling pain referred to ulnar area.	Recovery.	Elbow.	Ulnar.

TABLE VII.—

Serial No.	*Name.*	*No. of months between injury and healing of wound.*	*No. of months between healing of wound and operation.*	*No. of months between operation and last examination.*	*Electrical re-actions before operation.*	*Electrical re-actions at last examination.*	*Sensory loss before operation.*	*Signs of sensory recovery at last examination.*
449.	G.G.	2.	6.	3.	F.C.U. F.A. G.+ others F.+	F.C.U. F. weak others F. good.	E & P.	Nii.
450.	G.P.	1.	3.	3.	F.A. G.+	F.A. G.+ except supinator longus slight.	E & P.	Nil.
483.	M.V.	3.	7.	3.	F.+	F. good.	No loss.	N.A.
17.	G.G.	1.	6.	4.	F.+	F.+	E & P.	Nil.
89.	F.H.	1.	10.	4.	F.+ except abd. and opp. poll.	F.+ except abd. and opp. poll.	E & P.	Protopathic returning.
457.	S.B.	1.	12.	4.	F.A.	F.A.	E & P.	Protopathic returned.
433.	J.McG.	4.	17.	4.	F.A. ext. pop. F.A. int. pop. except flexor long. dig. and flexor long. hall.	F.+ in all.	E only.	Epicritic returning over musc. cut. area.
25.	H.F.	5.	2.	4.	F.A.	F.+ ext. pop. F.A. G.+ int. pop.	E & P.	Nil.
42.	A.H.	1.	7.	4.	F.+	F.+	E & P.	Both E & P. returning.
44.	J.S.	4.	3.	4.	F.A.	F.+	E & P.	Nil.

NEUROLYSES (*continued*).

Vol. power in muscles below lesion before operation.	*Vol. power in muscles below lesion at last examination.*	*No. of months after operation before recovery commenced.*	*Other signs of recovery.*	*Resulting condition.*	*Site of injury.*	*Nerve involved.*
Fair.	Good. F.C.U. fair.		Percussion over nerve at wrist, tingling pain referred to ulnar area.	Recovery.	Lower third arm.	Ulnar.
Nil.	Nil except sup. longus slight.		Percussion over nerve at elbow, tingling pain referred to radial area.	No change.	Axilla.	Musculo-spiral.
Fair except small thumb muscles.	Good in all.			Recovery.	Upper third forearm.	Median.
Nil.	Slight.			Improvement.	Middle third arm.	Ulnar.
Nil.	Nil.			Slight improvement.	Upper third forearm.	Median.
Nil.	Nil.		Percussion over nerve at wrist, tingling pain referred to median area.	Slight improvement.	Lower third forearm.	Median.
Slight.	+ in all.			Recovery.	Middle third thigh.	Sciatic.
Nil int. pop. Slight ext. pop.	+ Ext. pop. Nil. Int. pop. except gastroc. and flexor long. dig.			Improvement.	Buttock.	Sciatic.
Slight.	Good.			Recovery.	Lower third forearm.	Median.
Nil.	+	V. 4 mths.	Percussion over nerve middle third forearm, tingling pain referred hypo-thenar eminence.	Recovery.	Middle third arm.	Ulnar.

TABLE VII.—

Serial No.	*Name.*	*No. of months between injury and healing of wound.*	*No. of months between healing of wound and operation.*	*No. of months between operation and last examination.*	*Electrical re-actions before operation.*	*Electrical re-actions at last examination.*	*Sensory loss before operation.*	*Signs of sensory recovery at last examination.*
60.	S.B.	5.	2.	4.	F.A.	F.+	E & P.	Protopathic returned.
232.	F.H.	3.	5.	4.	F.+	F.+	E & P.	Protopathic returned.
93.	W.McG.	1.	5.	4.	F.A. G. fair.	F.A. G. fair.	E & P.	Protopathic returned over external pop. supply only.
11.	F.P.	1.	5.	4.	F. slight.	F.+ in all.	E & P. lost.	Nil.
347.	M.W.	5.	4.	5.	F.A.	F.A. G.+	E & P.	Protopathic returning.
353.	W.L.	3.	6.	5.	F.A.	F.+	E & P.	Protopathic returned. Epicritic commencing to return.
356.	J.H.F.	7.	2.	5.	F.+	F.+	E & P.	Protopathic returned.
364.	J.B.	6.	5.	5.	F.A.	F.+	E & P.	Protopathic returned.
373.	R.F.J.	2.	7.	5.	F.A. G.+	F.+	E & P.	Protopathic returned.
4.	R.F.	5.	13.	5.	F.A. G.A.	F.+	E only.	Nil.
4.	R.F.	5.	13.	5.	F.A. G.A.	F.A. G.A.	E & P.	Nil.
3.	D.G.	2.	19.	5.	F. slight.	F. good.	No loss.	N.A.

NEUROLYSES (*continued*).

Vol. power in muscles below lesion before operation.	*Vol. power in muscles below lesion at last examination.*	*No. of months after operation before recovery commenced.*	*Other signs of recovery.*	*Resulting condition.*	*Site of injury.*	*Nerve involved.*
Nil.	Nil.			Improvement.	Lower third forearm.	Median.
+	Good.			Recovery.	Middle third arm.	Median.
Nil.	Nil.		Percussion over ext. and int. pop. nerves at knee, tingling pain referred to areas of cutaneous supply.	Slight improvement ext. pop. No change int. pop.	Upper third thigh.	Sciatic.
Very slight.	Slight.		Tingling pain on percussion over nerve at wrist referred to ulnar area.	Slight improvement.	Middle third forearm.	Ulnar.
Nil.	Nil ext. pop. Slight int. pop.			Improvement.	Upper third thigh.	Sciatic.
Slight.	Good.			Recovery.	Upper third forearm.	Median.
Very slight.	Good.			Recovery.	Lower third arm.	Musculo-spiral.
Nil.	Good except peroneus longus.	P. 2 mths.		Recovery.	Upper third thigh.	External half sciatic.
Nil.	+	P. 3 mths.		Recovery.	Lower third arm.	Musculo-spiral.
Slight.	Fair.			Improvement.	Knee.	External popliteal.
Slight.	Fair.			Improvement.	Knee.	Internal popliteal.
Slight.	Good.			Recovery.	Upper third forearm.	Median.

TABLE VII.—

Serial No.	*Name.*	*No. of months between injury and healing of wound.*	*No. of months between healing of wound and operation.*	*No. of months between operation and last examination.*	*Electrical re-actions before operation.*	*Electrical re-actions at last examination.*	*Sensory loss before operation.*	*Signs of sensory recovery at last examination.*
441.	J.Y.	2.	3.	5.	F.A.	F.+ except abd. poll.	E only.	Nil.
441.	J.Y.	2.	3.	5.	F.+	F.+	E & P.	Nil.
79.	E.C.	1.	4.	5.	F.A.	F.A. except supinator longus F.+	E & P.	Protopathic returning.
97.	E.H.	1.	6.	5.	F.A. G.A.	F.+ except F.L.P. and small muscles.	E & P.	Protopathic returning.
97.	E.H.	1.	6.	5.	F.A. G. faint.	F.A. G.+ except F.C.U. and flex. prof. dig.	E & P.	Protopathic returning.
480.	J.D.	3.	6.	5.	F.A.	F.+	E & P.	Protopathic returned.
480.	J.D.	3.	6.	5.	F.A. except gastroc. and tib. post.	F.+ in all.	No loss.	N.A.
460.	W.H.M.	1.	4.	6.	F.A. int. and ext. pop. except tib. ant.	F.+ except int. pop., F.A. G. faint.	E & P.	Protopathic returned over ant. tibial area only.
440.	C.T.	3.	6.	6.	F. fair.	F.+ in all.	E & P.	Protopathic returned.
366.	J.C.	2.	5.	6.	F.A.	F.A.	E & P.	Nil.

NEUROLYSES (*continued*).

Vol. power in muscles below lesion before operation.	*Vol. power in muscles below lesion at last examination.*	*No. of months after operation before recovery commenced.*	*Other signs of recovery.*	*Resulting condition.*	*Site of injury.*	*Nerve involved.*
Nil.	+		Percussion over nerve lower third forearm, tingling pain referred to median area.	Recovery.	Middle third arm.	Median.
+	+		Percussion over nerve lower third forearm, tingling pain referred to ulnar area.	No change.	Middle third arm.	Ulnar.
Nil.	Good.	V. 1 mth.	Percussion over nerve at elbow, tingling pain referred to radial area.	Recovery.	Axilla.	Musculo-spiral.
Nil.	+ except F.L.P. and small muscles.		Percussion over nerve at elbow, tingling pain referred to median area.	Improvement.	Axilla.	Median.
Nil.	+ except intrinsics.		Percussion over nerve at elbow, tingling pain referred to ulnar area.	Improvement.	Axilla.	Ulnar.
Slight.	Fair.			Improvement.	Knee.	External popliteal.
Weak.	Good.			Recovery.	Knee.	Internal. popliteal.
Nil int. pop. slight ext. pop.	Nil int. pop. except gastroc. and tib. post. ext. pop.			Recovery ext. half; improvement int. half.	Middle thigh.	Sciatic.
Slight.	+ in all.		Tingling pain on percussion lower third forearm referred to median area.	Recovery.	Upper third right arm.	Median.
Nil.	Slight in flex. sub. others nil.			No change.	Elbow.	Median.

TABLE VII.—

Serial No.	*Name.*	*No. of months between injury and healing of wound.*	*No. of months between healing of wound and operation.*	*No. of months between operation and last examination.*	*Electrical re-actions before operation.*	*Electrical re-actions at last examination.*	*Sensory loss before operation.*	*Signs of sensory recovery at last examination.*
367.	A.B.	1.	7.	6.	F.A.	F.+ long ulnar muscles, F.A. intrinsics.	E & P.	Protopathic returned.
363.	J.T.E.	2.	1.	6.	F.A.	F.+	E & P.	Protopathic returned.
362.	J.E.H.	3.	6.	6.	F. slight.	F.+	E & P.	Protopathic returning.
357.	B.F.	1.	4.	6.	F.A.	F.A. G.+	E & P.	Protopathic returned.
423.	C.P.	2.	3.	7.	F.A. G.+	F.+ in all except abd. and opp. poll. F.A.	E & P.	Protopathic returning.
121.	J.B.	6.	3.	7.	F.A.	F.+	E & P. over total sciatic supply.	Protopathic returning over external popliteal supply.
144.	E.H.T.	2.	4.	7.	F.+	F.+	E & P.	Nil.
408.	J.A.L.	2.	9.	7.	F.A. G.A.	F.+	E & P.	Protopathic returning.
369.	H C.C.	5.	2.	7.	F.+	F.+	Nil.	Operation for causalgia has resulted in marked decrease in pain.
371.	W.J.C.	4.	5.	7.	F.+	F.+	No loss.	N.A.

NEUROLYSES (*continued*).

Vol. power in muscles below lesion before operation.	*Vol. power in muscles below lesion at last examination.*	*No. of months after operation before recovery commenced.*	*Other signs of recovery.*	*Resulting condition.*	*Site of injury.*	*Nerve involved.*
Nil.	Nil.	P. 5 mths.		Improvement.	Upper third arm.	Ulnar.
Nil.	Slight.			Improvement.	Axilla.	Median.
Nil.	Fair.			Improvement.	Left upper arm.	Musculo-spiral.
Nil.	Nil.			Improvement.	Upper third arm.	Ulnar.
Nil.	+		Percussion over nerve at junction lower and middle thirds in forearm, tingling pain referred to median area.	Recovery.	Middle third arm.	Median.
Very slight.	Good in all.			Recovery.	Lower third thigh.	Sciatic.
Slight.	Good.		Marked muscular contracture which existed before operation now practically disappeared.	Recovery.	Middle third forearm.	Ulnar.
Nil.	Fair.			Improvement.	Middle third arm.	Median.
Slight.	Good.			Recovery.	Buttock.	Sciatic.
Fair.	Good.			Recovery.	Upper third thigh.	Internal half sciatic.

TABLE VII.—

Serial No.	*Name.*	*No. of months between injury and healing of wound.*	*No. of months between healing of wound and operation.*	*No. of months between operation and last examination.*	*Electrical re-actions before operation.*	*Electrical re-actions at last examination.*	*Sensory loss before operation.*	*Signs of sensory recovery at last examination.*
451.	A.H.	4.	1.	7.	F.A.	F.+	E & P.	Nil.
432.	C.G.	1.	1.	8.	Ext. pop. F. fair. Int. pop. F.A. hamstrings F.+	Int. pop. F.A., all others F.+	E & P.	Protopathic returning.
189.	C.G.	1.	8.	8.	F.A.	F. good.	E & P.	Nil.
151.	V.H.	2.	2.	8.	F.A.	F.+ except abd. poll.	E & P.	Nil.
236	F.F.	1.	4.	9.	F.+	F.+	No loss.	No loss.
406.	J.F.	2.	2.	9.	F.A.	F.+ except opp. and abd. poll.	E & P.	E & P returning.
348.	G.H.	1.	4.	10.	F.A.	F.+	E & P.	Protopathic returned.
403.	J.J.	1.	10.	10.	No electrical reactions taken before operation.	F.A. ext. pop. F.+ int. pop.	E only.	Nil.
279.	J.T.W.	2.	9.	11.	F.+	F.+	E only.	Epicritic only lost over very small area.
284.	T.J.C.	2.	11.	11.	F.+	F.+	E only.	Epicritic commencing to return.
294.	C.C.	2.	3.	11.	F.A.	F.+ except abd. and opp. poll.	E & P.	Protopathic returned.

NEUROLYSES (*continued*).

Vol. power in muscles below lesion before operation.	*Vol. power in muscles below lesion at last examination.*	*No. of months after operation before recovery commenced.*	*Other signs of recovery.*	*Resulting condition.*	*Site of injury.*	*Nerve involved.*
Nil.	+	V. 6 mths.	Percussion over nerve 4 inches below scar, tingling pain referred to ext. pop. area.	Recovery.	Lower third thigh.	External popliteal.
Int. pop. slight, ext. pop. very slight.	Good in all.			Recovery.	Middle third thigh.	Sciatic.
Nil.	+			Recovery.	Wrist.	Median.
Nil.	Palmaris longus and flexor carpi radialis only.	V. 7 mths.		Improvement.	Upper third arm.	Median.
Nil.	Good.			Recovery.	Upper third arm.	Median.
Nil.	+ in all.			Recovery.	Lower third arm.	Median.
Slight.	Good.			Recovery.	Lower third. arm.	Ulnar.
Nil.	Slight ext. pop., fair int. pop.			Improvement.	Buttock.	Sciatic.
Fair.	Good.			Recovery.	Middle third arm.	Median.
Slight.	Good.			Recovery.	Middle third forearm.	Median
Nil.	+ except opponens and abd. pollicis.			Improvement.	Elbow.	Median.

TABLE VII.—

Serial No.	*Name.*	*No. of months between injury and healing of wound.*	*No. of months between healing of wound and operation.*	*No. of months between operation and last examination.*	*Electrical re-actions before operation.*	*Electrical re-actions at last examination.*	*Sensory loss before operation.*	*Signs of sensory recovery at last examination.*
294.	C.C.	2.	3.	11.	F.A.	F.A. except F.C.U. F. +	E & P.	Protopathic returned.
379.	T.B.	3.	8.	11.	F.+	F.+	E & P.	E & P returned.
436.	L.E.	2.	1.	11.	F.A.	F.+ except tib. post. and intrinsics.	E & P.	Protopathic returned.
2.	R.M.	3.	3.	11.	F.A. in all.	F.+	E only.	Nil.
442.	T.H.	3.	1.	12.	F.A.	F.A. G.+ in all.	E & P.	Protopathic returned.
376.	J.H.	5.	2.	12.	F.A.	F.+ in all.	E & P.	Protopathic returned.
223.	A.G.	3.	11.	12.	F.A.	F.+ in all.	E only.	Nil.
117.	J.W.C.	3.	11.	12.	F.A.	F.A. G.+	E & P.	Protopathic returned.
172.	F.W.M.	3.	9.	13.	+ except ext. long. hall. and ext. long. dig. A.	F. good except ext long. hall. ext. long. dig. F.A.	E only	Nil.
322.	A.L.	1.	11.	13.	F.+	F.+	E only.	Nil.
368.	P.B.	2.	5.	13.	F. slight.	F.+	E & P.	Nil.
314.	F.W.	3.	1.	13.	F.A. G.A.	F.A. G.+ except triceps F.+	E & P.	Nil.

NEUROLYSES (*continued*).

Vol. power in muscles below lesion before operation.	*Vol. power in muscles below lesion at last examination.*	*No. of months after operation before recovery commenced.*	*Other signs of recovery.*	*Resulting condition.*	*Site of injury.*	*Nerve involved.*
Nil.	Nil except F.C.U. slight.			Improvement.	Elbow.	Ulnar.
Slight.	Good.			Recovery.	Middle third forearm.	Median.
Nil.	+ in all.		Tingling pain on percussion over nerve at knee referred to int. pop. area.	Recovery.	Middle third thigh.	Internal popliteal.
Very slight.	Fair.			Improvement.	Upper third thigh.	Internal half sciatic.
Nil.	Nil except flexor carp. rad., palmaris long., and F.L.P.			Improvement.	Upper third arm.	Median.
Nil.	Good.			Recovery.	Middle third thigh.	Sciatic.
Slight.	+ in all.			Recovery.	Junction upper and middle third forearm.	Median.
Nil.	Nil.	P. 4 mths.		Slight improvement.	Knee.	External popliteal.
Nil.	Fair.			Improvement.	Lower third thigh.	External popliteal.
Nil.	Good.			Recovery.	Lower third arm.	Ulnar.
Slight.	+			Recovery.	Lower third forearm.	Median.
Nil.	Slight.			Slight improvement.	Upper third arm.	Musculo spiral.

TABLE VII.—

Serial No.	*Name.*	*No. of months between injury and healing of wound.*	*No. of months between healing of wound and operation.*	*No. of months between operation and last examination.*	*Electrical re-actions before operation.*	*Electrical re-actions at last examination.*	*Sensory loss before operation.*	*Signs of sensory recovery at last examination.*
390.	S.G.	3.	8.	14.	F.A.	F.+	E & P.	Protopathic returned.
302.	J.J.M.	2.	6.	14.	F.A.	F.A. G.+	E & P.	Protopathic returned.
235.	J.E.	2.	6.	14.	F.A.	F.+	E only.	Nil.
417.	H.W.	2.	10.	15.	F.A.	F.+ except ext. long. hall. F.A. G.+	E only lost over musc. cut. and ant. tib. areas.	Nil.
154.	M.W.	3.	18.	15.	F.A.	F.+	E only.	Epicritic commencing to return.
452.	S.H.	2.	6.	15.	F.A.	F.+	E & P.	Nil.
156.	M.S.	5.	3.	17.	F.A.	F.+ in all.	E & P.	Protopathic returned.
395.	J.W.	6.	1.	17.	F.A.	F.A. G.+	E & P.	Nil.
327.	J.H.	1.	8.	17.	F.A. G.A.	F.A. G.A. except flex. carp. Rad. F.+	E & P.	Nil.
137.	M.G.	2.	3.	19.	F.A.	F. fair.	E & P.	Protopathic returned.
237.	W.S.	3.	4.	18.	F.A.	F.+	E & P.	Nil.

NEUROLYSES (*continued*).

Vol. power in muscles below lesion before operation.	*Vol. power in muscles below lesion at last examination.*	*No. of months after operation before recovery commenced*	*Other signs of recovery.*	*Resulting condition.*	*Site of injury.*	*Nerve involved.*
Nil.	Slight.			Improvement.	Upper third forearm.	Ulnar.
Nil.	+	V. 8 mths.	Radiating pains on percussion over ext. pop. nerve at knee.	Recovery.	Middle third thigh.	External half of sciatic.
Nil.	Good.	V. 6 mths.		Recovery.	Middle third forearm.	Ulnar.
Nil.	Nil.			Slight improvement.	Knee.	External popliteal.
Nil.	Slight.		Diminished wasting.	Improvement.	Middle third forearm.	Ulnar.
Nil.	Slight.		Percussion over nerve at elbow, tingling pain referred to radial area.	Improvement.	Upper third arm.	Musculo-spiral.
Nil.	+ in all.			Recovery.	Shoulder.	Ulnar.
Nil.	Nil.			No change.	Upper third forearm.	Ulnar.
Nil.	Nil.			No change.	Lower third arm.	Median.
Nil.	+	V. 9 mths.		Recovery.	Middle third arm.	Musculo-spiral.
Nil.	Good.	V. 1 mth.	Percussion over nerve at wrist, tingling pain referred to ulnar area.	Recovery.	Middle third forearm.	Ulnar.

TABLE VII.—

Serial No.	*Name.*	*No. of months between injury and healing of wound.*	*No. of months between healing of wound and operation.*	*No. of months between operation and last examination.*	*Electrical re-actions before operation.*	*Electrical re-actions at last examination.*	*Sensory loss before operation.*	*Signs of sensory recovery at last examination.*
275.	J.H.	3.	1.	20.	F.A.	F.+ int. F.A. ext.	E only.	Nil.
404.	H.W.P.	3.	1.	22.	F.A.	F.A. G.+	E & P.	Nil.
352.	W.L.	3.	1.	22.	F.A.	F.A.	E & P.	Protopathic returned.
218.	M.B.	2.	1.	24.	F.A.	F.A.	E & P.	P commencing to return.
304.	J.R.	1.	4.	24.	F.A.	F.+ except flex. long. poll. and abd. poll.	E & P.	Nil.
418.	M.G.	1.	2.	34.	F.A.	F.A.	E & P.	E & P returned.
		Tendon transplantation 8 mths. after nerve operation.						

NEUROLYSES (*continued*).

Vol. power in muscles below lesion before operation.	*Vol. power in muscles below lesion at last examination.*	*No. of months after operation before recovery commenced.*	*Other signs of recovery.*	*Resulting condition.*	*Site of injury.*	*Nerve involved.*
Nil.	+ internal, nil external.			Recovery internal half, no change external half.	Middle third thigh.	Sciatic.
Nil.	Nil.			No change.	Lower third forearm.	Ulnar.
Nil.	Nil.			Slight improvement.	Upper third thigh.	Sciatic.
Nil.	Nil.			Slight improvement.	Shoulder.	Ulnar.
Nil.	+ in all except abd. and opp. poll.	V. 7 mths.	Percussion over nerve middle forearm, tingling pain referred to median area.	Improvement.	Upper third arm.	Median.
Nil.	Nil in musculo-spiral muscles.			Slight improvement.	Middle third arm.	Musculo-spiral.

TENDON TRANSPLANTATION AND TENDON FIXATION IN IRREPARABLE INJURY TO PERIPHERAL NERVES

BY

T. P. MacMURRAY, Captain R.A.M.C.,
Surgeon to Special Military Surgical Hospital, Alder Hey, Liverpool

TENDON TRANSPLANTATION AND TENDON FIXATION IN IRREPARABLE INJURY TO PERIPHERAL NERVES

It is found that in every series of operations for injuries of peripheral nerves in at least 5 per cent. of the cases end-to-end apposition of the severed portions of the injured nerve cannot be obtained. This inability is due to two causes—either extensive loss of nerve tissue, or ankylosis of joints in the neighbourhood which prevents suitable relaxation of the tissues. Both of these conditions may present themselves in any particular case, and vary very markedly with the different nerves involved, but the amount of lost tissue which can be compensated for depends on the nerve injured, and also upon other conditions which affect it very materially. Thus a median nerve may be completely destroyed for four or four and a half inches in the upper part of its course, and yet by complete flexion of a mobile elbow the gap can be obliterated and apposition of the healthy nerve ends obtained without tension.

If, however, the elbow-joint, or to a lesser extent the shoulder or wrist joint, is ankylosed, then the size of the gap which can be bridged over between the two ends is very much smaller, its length depending largely on the position in which the ankylosis has occurred.

As the ulnar nerve lies close behind the internal condyle of the humerus, it is very frequently involved in injuries round the elbow where a bone lesion may or may not have occurred. A gap in the ulnar nerve of at least three and a half inches can be obliterated in this area by transferring the nerve from the posterior to the anterior surface of the flexed elbow-joint, and a good apposition secured.

Thus we find that both in the upper and in the lower limbs large gaps in the peripheral nerves can, under suitable conditions, be obliterated, and a perfect end-to-end suture of the divided nerve ends become possible, but there is a certain limit beyond which a loss of nerve tissue cannot be compensated.

Many suggestions have been made as to the means by which this loss of tissue can be made good, and various operations have been devised and performed to restore the continuity and function of the divided nerve. A flap of nerve has been taken from the upper severed end, and turned down and sutured to the lower end. This undoubtedly restores the continuity of nerve tissue, but this restoration of tissue is in reality more apparent than real, and the turned-down flap probably acts only as a scaffolding for the downward-growing fibres. If this is not so, then,

in the turned-down nerve flap, the fibres which originally were afferent are now supposed to be able to conduct efferent stimuli, and these efferent fibres likewise must then become conductors of afferent stimuli.

If we accepted the theory that the direction of stimulus in a nerve fibre is reversible then there would be no hindrance to the usefulness of such a nerve-flap operation; but, unfortunately, the experience of most surgeons is, that while such an operation may be followed by slight improvement of sensation or function, the restoration is never complete, and the results obtained hitherto do not encourage the extensive use of this method of treatment.

Many other schemes have been brought forward, including the removal of a portion of the long bone in the affected area to relax all structures, and so bring the severed nerve ends in apposition: the implantation of a tube of vein, fascia, or decalcified bone down which the fibres should grow to meet those from the other end; or the implantation of a portion of another nerve or nerve tissue, either from some other less important nerve in the patient's body or from some animal.

Unfortunately, the result has been uniformly bad up to the present with all these methods of implantation, therefore the surgeon is forced to look for some other means which will restore the function of a limb which has been rendered useless, either in part, or altogether, by an irretrievable damage to its nerve supply.

It may then be taken as a guiding rule that unless end-to-end apposition of the severed ends of an injured nerve can be obtained the prognosis is bad, but, unfortunately, all the cases of nerve division in which end-to-end suture is obtained do not recover.

Statistics of nerve operations and their results are now in the making, so that it is as yet impossible to state what the normal percentage of recovery after nerve suture really is. However, we know from our experience that, although the prognosis is extremely encouraging, there is a certain percentage of cases which even under apparently the most perfect conditions do not recover.

Experience shows that the prospect of functional recovery after a nerve suture depends on the occurrence of sepsis either at the time of injury or at the operation, the condition of the parts supplied by the paralysed nerve, and the accuracy of the suture.

We frequently find in war wounds that several factors militate against a good result. Thus there may be a compound fracture which was allowed to discharge for twelve or eighteen months, or even longer, in addition to the nerve injury, and the muscles supplied are now completely atrophied, show no reaction to electrical stimulus, and that all the joints are stiff from prolonged splinting. Then arises the question whether instead of waiting another two or three years for a very problematic

recovery of function after nerve suture, it would not be better to resort at once to the expediency of tendon transplantation, and so restore function to the otherwise useless limb. Therefore the best rule to follow in regard to nerve suture is that when end-to-end suture of the divided nerve ends cannot be accomplished, tendon transplantation should be resorted to where this is possible.

In a case where nerve suture has apparently been successfully accomplished, and no recovery takes place, the possibility of tendon transplantation should be considered as affording the best means of restoring function which is lost. Recovery after nerve suture occurs at very varying intervals. Thus complete recovery of motor function may take place after suture of a nerve, such as the musculo-spiral, in three months, and, in another case, the recovery may only begin to appear after a year or eighteen months or longer. If, however, a case of nerve suture shows no sign of recovery of function after two years' continuous treatment, then undoubtedly a tendon transplantation should be effected.

Tendon transplantations in these cases may be defined as the means of restoring voluntary movements which have been lost owing to the irretrievable destruction of the muscles or of the nerve supplying the muscles normally producing these movements.

Tendon transplantation or tendon fixation is, fortunately, applicable to every case of peripheral nerve injury, both in the upper or lower limb, but in considering the various transplantations the aim and object of the operation differs somewhat with the situation of the injury. Thus, in the upper limb, the most important thing to secure is mobility with the greatest amount of stability compatible with this voluntary power. In the lower limb, however, while active movement is desirable from every point of view, yet the chief end to be attained is stability of the limb for weight-bearing purposes.

Before discussing in detail the various tendon transplantations which can be adopted, there are certain rules which must be clearly understood and closely followed if a successful result is to be obtained from the transplantation.

First. The joints upon which the transplanted tendons are called upon to act must be rendered as mobile as possible.

Second. The muscle and tendon for transplantation must be of sufficient strength to accomplish the action for which it is to be employed.

Third. The transplanted muscle and tendon must pursue a straight course between its origin and its insertion, and should not work obliquely or round an angle.

Fourth. The transplanted muscle must be attached under slight tension.

One of the most frequent causes of disappointment in tendon transplantation is due to the expectation that the transplanted tendon will correct a fixed deformity. In a case of paralysis or paresis of the peronei tendons due to nerve injury or to destruction of muscle, the foot is frequently allowed to be held in a position of marked varus deformity, and owing to adhesions, and to contraction of the tendo Achillis and plantar fascia, it becomes fixed in this position. If while the foot is in this position, the tibialis anticus tendon, which under proper conditions is a very suitable tendon to use to produce eversion of the foot, is transplanted and inserted into the outer aspect of the tarsus, the result is a failure because the newly-inserted tendon is not sufficiently strong to correct the existing deformity. Correction of a faulty position of joint should always be secured before any tendon transplantation is attempted, so that the tendon may act on a mobile and not on a rigid part.

Frequently in cases of nerve injury, particularly in the upper limb, treatment has been carried on by splinting combined with massage, &c., of the limb for many months. Unfortunately, however, the splints are not always devised of the most suitable type, so that rigidity frequently follows their prolonged application. This is probably seen most frequently in a hand which, after an injury to the musculo-spiral nerve, has been kept fully dorsiflexed, with the fingers extended on a flat splint, for a period of many months. When the splints are removed it is found that all the joints of the fingers and hand are rigid, but especially the metacarpo-phalangeal range of joints. These are frequently in a position of hyper-extension, and so rigid that practically no palmar flexion can be obtained. This troublesome condition is quite avoidable by flexion of the splint so that the metacarpo-phalangeal and interphalangeal joints are each flexed to an angle of 15° when fixed on the splint, and when the rigidity is present it must be completely overcome before any attempt is made at tendon transplantation, and the massage and forced flexion of the fingers which is necessary can be applied much more effectively before than after tendon transplantation.

Probably the most important detail of the operation is the observance of the rule that there must be no obliquity of pull, or angling of the transplanted tendon. Failure to observe this fundamental principle is usually due to the use of very short incisions through which the tendon to be transplanted is taken and pulled from its old line of action into its new one. Unless the line of the muscle to be transplanted is seen in the operation wound at the same time as the tendon, there can be no surety that the tendon is not still firmly held in its sheath or is not being drawn round some strong process of deep fascia, producing an angle and thereby destroying any strength which it would possess in its new position.

The risk from increasing the length of the incision is so small under

a good aseptic technique, and the advantages to be obtained from the longer incision are so great, that a long incision is much to be preferred to multiple small ones, which can never give the same view of the field of operation.

When the transplanted tendon is being inserted either into bone or into other tendons, slight tension should be used, otherwise the muscle will be subsequently required to contract so much, in order to pull in its slack, that its action on the tendons into which it is inserted is markedly diminished, and may be altogether lost. This is well illustrated when, for destruction of the musculo-spiral nerve, the flexor carpi ulnaris and the flexor carpi radialis are inserted into the extensors of the fingers and thumb. Unless the tendon suture is performed with the hand and fingers dorsi-flexed most of the action of the flexor muscles will be employed in raising the fingers from whatever palmar flexed attitude they occupied at the time of operation.

TENDON TRANSPLANTATION IN THE UPPER LIMB

Injuries of the brachial plexus are comparatively common in war wounds, and one finds more of these injuries implicating the upper rather than the lower part of the plexus. This is probably explained by the relation of the lower part of the plexus to the subclavian artery and vein, so that an injury of the lower end of the plexus is frequently associated with injury of either of these two structures, and, in all probability, fatal hæmorrhage.

Suture of the upper part of the brachial plexus is followed by a high percentage of complete recoveries, but in some of the cases, owing to the position or extent of the injury, suture of these nerve trunks is impossible, so that some other form of treatment is necessary. Lesion of the fifth or fifth and sixth cervical nerve roots is followed by paralysis of the muscles of the shoulder girdle, which include the deltoid, supra and infra spinatus, and biceps. If no operation can be devised to restore the function of these nerves, the arm will hang by the side with no power of abduction beyond the pull of the trapezius, &c., on the scapula. For this disabling condition various tendon and muscle transplantations have been performed with very poor success. The upper part of the trapezius, either by itself or in conjunction with the clavicular portion of the pectoralis major, has been used to reinforce the deltoid, but the functional result in my hands has invariably been unsatisfactory. Here undoubtedly tendon transplantation cannot restore the function which is lost, and it is wiser to perform an arthrodesis of the shoulder-joint as it is quite certain that no nerve implantation or lateral anastomosis can restore function through the normal channels. The shoulder-joint should be arthrodesed with the arm fixed in a position of 75° abduction from the body and 30° in

front of the coronal plane. The unparalysed muscles which act on and move the scapula now act on the arm through the fixed shoulder-joint. The scapula itself becomes more movable, and the arm, instead of hanging limply by the side, can be fully abducted and brought forward, so that the function of the limb is restored to a very large degree.

LOSS OF THE MUSCULO-SPIRAL NERVE

Irretrievable destruction of the musculo-spiral nerve is more commonly seen than that of any other nerve in either the upper or the lower limb. The injury may occur at any part of its course, but the most frequent site is at the back of the humerus. Here it is frequently associated with an extensive compound fracture of the humerus, which has involved a large portion of the nerve, resulting in the impossibility of end-to-end suture. Frequently, however, the same complete loss of power to dorsiflex the wrist or extend the fingers is found to be due to an extensive wound of the back of the forearm in which the muscles have been destroyed. In either of these two circumstances the condition present is a complete paralysis of the extensors of wrist and fingers with full power in all the muscles of the anterior aspect of forearm.

The principal question is whether there are any muscles on the flexor aspect of the forearm whose action can be transposed without materially diminishing the usefulness and power of flexion of the hand, wrist, and fingers. In discussing this problem we realize that, in the position of dorsiflexion of the wrist-joint, the power of grip and usefulness of the hand is at its greatest. This can easily be proved by any one. The fingers can be closed when the wrist is palmar flexed, but measurement of the strength of this closure shows it to be very much less than in the former position, and strong closure is accompanied by a feeling of cramp in the flexor muscles themselves. This is due to the flexor muscles being forced to contract through more than their normal range in order to produce closure of the fingers, because the first part of the contraction is used solely in tightening up the flexor tendons which have been made slack by the flexed position of the wrist-joint, whereas, with the wrist in dorsiflexion, all the muscle contraction acts towards closure of the fingers. Therefore, for the most advantageous use of the hand and fingers, the wrist should be dorsiflexed, and this action is normally produced by the combined action of the three dorsiflexors of the wrist. These are the extensor carpi radialis longior, the extensor carpi radialis brevior, and the extensor carpi ulnaris.

We know from the work of Sherrington that when any movement of a joint is produced by contraction of the muscles causing that particular movement, it is accompanied always by a reflex inhibition of the opposing group of muscles which produce the directly opposite action. Therefore,

when the wrist is being placed in the position of greatest strength, that is, in dorsiflexion, there is a contraction of the extensors with a simultaneous reflex inhibition of the flexors of the wrist which are thus thrown completely out of action and take no part in most of the normal movements of the hand. It is found that complete loss of action of the flexor carpi radialis and the flexor carpi ulnaris does not cause any marked loss of power in the movements of the hand or fingers, and the only movement which seems to be lost thereby is palmar flexion of the wrist with the fingers in a position of full extension.

The muscles which produce supination of the forearm are the supinator longus and brevis and the biceps, and the muscles which produce pronation are the pronator radii teres and the pronator quadratus. With complete destruction of the musculo-spiral nerve the biceps alone is left to produce supination, and the pronators are left unaffected.

The tendency undoubtedly exists for the arm to lie in a position of marked pronation, because the two active pronators are assisted by the force of gravity, which tends to pull the forearm into this position, so that the loss of the pronating action of one of these muscles does not hinder the active pronation of the forearm, but tends rather to equalize the powers of supination and pronation.

We know from experience of cases of infantile hemiplegia in which the pronator radii teres is extremely contracted, that complete division of the tendon or transplantation of it into the extensors does not cause a loss of power of pronation. Therefore this muscle may be used for transplantation into the extensor aspect without any appreciable loss of voluntary power. Situated on the anterior aspect of the forearm, and inserted into the anterior annular ligament and palmar fascia, is the small variable palmaris longus muscle, which in its action duplicates the flexor carpi radialis and ulnaris muscles. The palmaris longus may be used for transplantation (Figs. 122 and 123), but as a routine its use is open to several objections; because, although it occasionally may be quite strong, it is often very small indeed, and in a certain number of cases absent altogether. Therefore it cannot be relied upon like any of the other muscles, which are always present and which are reliable as to position and size. When any flexor muscles are required for transplantation into the extensor aspect of the forearm, the flexor carpi radialis, flexor carpi ulnaris, and pronator radii teres can be used; and if it is found present, and of sufficient strength, the palmaris longus can safely be used also without danger of causing loss of power in any important action of the hand or fingers.

We find that the first three of these four muscles, namely, the flexor carpi radialis, flexor carpi ulnaris, and the pronator radii teres, can always be relied upon as regards their presence and strength.

The pronator radii teres is a short, broad, flat muscle, as wide at its insertion as at its origin at the inner condyle of the humerus. It does not narrow down, as most muscles do, into a round tendon, but is inserted by a broad flat tendinous mass, of not more than half an inch in length, into the outer aspect of the radius. This insertion lies directly under the supinator longus, and just in front of the extensor carpi radialis longior

FIG. 122.—Showing palmaris longus tendon divided close to the annular ligament.

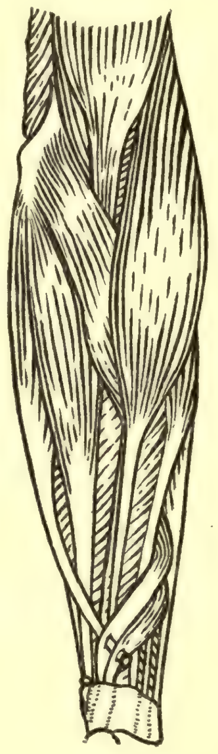


FIG. 123.—Showing palmaris longus tendon brought round the outer aspect of the forearm and sutured into the extensors of the thumb.

FIG. 124.—Showing origin, course, and insertion of pronator radii teres.

and brevior (Fig. 124). The tendon of the flexor carpi radialis is long, and begins about the middle of the forearm, but the tendon of the flexor carpi ulnaris is only about 3 in. in length on its superficial aspect and about 2 in. on its deep aspect where the fibres of origin from the ulna extend low on the bone. In the tendon transplantation for musculo-spiral nerve destruction we use the pronator radii teres to produce extension of the wrist, by inserting it into the two radial extensors, and the

flexor carpi radialis and flexor carpi ulnaris to produce extension of the fingers and thumb by insertion into these tendons.

Technique of the operation. A long J-shaped incision is made over the back and outer side of the lower part of the forearm. The long arm of the J passes up the radial side of the forearm and extends as high as the insertion of the pronator radii teres. The loop of the incision lies on the back of the carpus and ends on the middle of the posterior aspect of the wrist-joint. The flexor carpi ulnaris is then approached through a vertical incision about 5 in. in length over the anterior aspect of the lower portion of the muscle and tendon.

These extensive incisions are used in preference to several small separate incisions, because by means of them the receiving tendons and the whole course of the tendons which are to be transplanted can be inspected and thus all chance of 'angling' can be avoided. The importance of this precaution in the technique cannot possibly be exaggerated, because a transplanted tendon which is forced to work obliquely round an angle of bone or of fascia works at best, badly, and frequently will not perform the action for which it has been transplanted, although in all other essentials as regards strength, &c., it may easily be capable of performing its allotted task. Directly underneath the long arm of the incision lies the supinator longus, which is situated directly over the insertion of the pronator radii teres. Lying parallel to and just behind the supinator longus are the extensor carpi radialis longior and brevior (Fig. 125), and by retracting the supinator longus posteriorly, the relation of the insertion of the pronator radii teres to the two radio-carpal extensors can be seen. In order to raise the pronator radii teres from the radius, it is necessary to take the periosteum of the bone in addition to the short tendon of the muscle. The utmost care must be used here in order that no portion of the tendon is left attached to the bone. This can be safely attempted, as the most careful study by means of X-rays of the removed periosteum has never shown any bone formation occurring in the transplanted tendon.

After freeing the pronator radii teres from the radius the flexor carpi radialis should be divided close to its insertion (Fig. 126), and similarly the flexor carpi ulnaris should also be cut as low as possible. In the case of the flexor carpi ulnaris the muscle fibres of origin from the inner border of the ulna extend down close to the wrist-joint, and if these are left intact will cause a marked 'angling' of the tendon when transplanted. The fibres of origin of the flexor carpi ulnaris from the ulna should now be divided for at least 4 in. above the lower end of the ulna, and the strong fascia holding the flexor carpi radialis in position should be divided right to the top of the long arm of the incision. The wrist and fingers should now be retained in complete dorsiflexion and the thumb in full abduction during the completion of the operation, as it is

necessary that the transplantation should be performed with a moderate amount of tension on the transplanted tendons in order to procure their

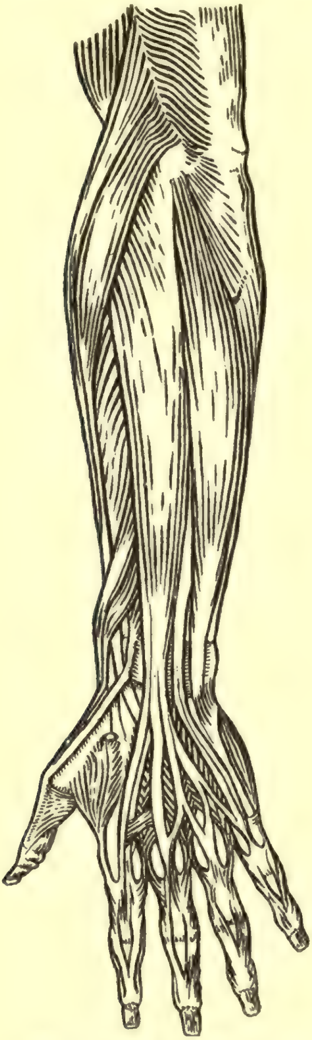


FIG. 125.—Showing relations of radio-carpal extensors on back of forearm.

FIG. 126.—Showing flexor carpi radialis divided at annular ligament.

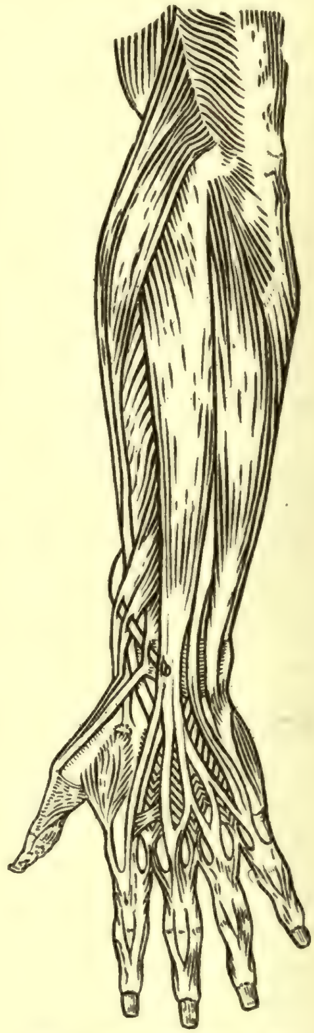


FIG. 127.—Showing flexor carpi radialis tendon brought round the outer side of the forearm and inserted through the extensors of the thumb and the extensor tendon of the index finger.

best possible action. After pulling aside the supinator longus, the two radio-carpal extensors should be split longitudinally for about three-quarters of an inch, as low down as it is possible for the insertion of the

pronator radii teres, which should be passed through the slit in each of the tendons. The pronator teres should now be sutured into the tendons through which it has been passed, and the suturing should be performed to half of each tendon only. This is a rule which should always be strictly adhered to, because if the suture encloses the whole of the tendon there is a loss of blood supply in the receiving tendon below the suture, and this leads to much increased stretching of the tendon and marked loss of function.

The flexor carpi radialis should now be inserted into the three extensors of the thumb and the extensor of the index finger (Fig. 127). These two digits normally work together, and it is found that after transplantation their action is best when they are moved by the same transplanted tendon. The flexor carpi ulnaris is now brought round the ulnar border, and is inserted into the extensors of the other three fingers, and here it should be noted that the extensor of the little finger lies in a special compartment on the back of the radius, and should always be sought for separately. It is never necessary to wrap any membrane or fascia round the line of suture of the tendon if any of the methods of burying the cut tendon ends are followed. This is usually done by cutting the end of the tendon obliquely and suturing the edges of the tendon into which it has been transplanted. Here the cut tendon end is completely covered over by normal smooth, shining tendon and all chance of adhesions to the rough end is thereby obliterated. The deep fascia is sewn separately along the whole course of the incision, and then the skin. During **the whole course of the tendon suture, the hand and fingers are held fully dorsiflexed,** and the limb is then placed on a splint which keeps the wrist in full dorsiflexion with the metacarpo-phalangeal and interphalangeal joints flexed at an angle of approximately ten degrees. The limb is kept in this position for a fortnight, after which massage and electrical stimulation of the transplanted tendons are employed with the limb still held in hyperextension, until the transplanted tendons have developed sufficient power to hold the wrist in the hyperextended position. This position should be maintained continuously until it can be held voluntarily by the transplanted tendons. Slight voluntary movements are allowed in another two weeks and full voluntary movement after eight weeks. Any subsequent tendency to loss of full extension is usually corrected by the reapplication of the splint, putting the limb into the original position for a few days combined with massage and electrical treatment as before.

This operation has now been employed by me in about twenty cases. In every case the patient has been able to dorsiflex the wrist with the fingers closed, and then to extend the fingers while the wrist remains in dorsiflexion.

In one case in which I operated for aneurism of the subclavian artery, it was found that in addition to the aneurism there was a complete destruction of the musculo-spiral nerve for a distance of at least 4 in. Three weeks after the operation on the artery, tendon transplantation was performed, and nine months after the transplantation the patient had passed a full Army gymnastic course, had been given a commission, and returned to the fighting line in France, where he remained for more than a year before again being wounded. This is the only patient of mine up to the present who has returned to active service, but every other man without exception has been able to return to work with a useful instead of with a comparatively useless limb.

DESTRUCTION OF THE MEDIAN NERVE IN THE ARM

Cases in which this nerve has been so extensively damaged that end-to-end suture cannot be performed are fortunately rare on account of the great possibility of closing in a gap in the nerve by flexion of the elbow and wrist. Unfortunately the number of cases in which end-to-end suture of the nerve has been performed and no sign of any recovery taken place, even after a period of three or more years, is very much greater than is the case with the musculo-spiral nerve. With complete loss of the median nerve there is paralysis of the flexor carpi radialis, flexor sublimis digitorum, flexor longus pollicis, and the outer half of the flexor profundus digitorum and palmaris longus. The marked loss of use in the hand is due chiefly to the loss of power of flexion of the thumb and index finger as there is usually some slight power of flexion of the middle finger.

A very useful hand can be obtained by transplanting the extensor carpi radialis longior into the flexor longus pollicis, and by suturing the two outer inactive tendons of the flexor profundis digitorum to the two inner active tendons of the same muscle.

A vertical incision is made, about 3½ in. long, from the upper border of the anterior annular ligament parallel to the length of the arm and close to the inner side of the radial artery. Another incision parallel to this one and of 4 in. in length is made at the same level on the back of the radius over the extensor carpi radialis longior tendon. The extensor carpi radialis longior is now divided close to its insertion, and the tendon is freed from fascia to the upper limit of the incision. The tendon is now passed under the bridge of skin and brought to the anterior aspect of the arm. The thumb being flexed slightly into the palm, the transplanted tendon is sutured to the flexor longus pollicis. The line of suture here should not be thick because any marked increase in bulk in the tendon at the line of suture prevents its fine working in the sheath which lies on the anterior aspect of the thumb. Through the same anterior incision

the flexor sublimis tendons and the median nerve are now retracted inwards, and after making the adjacent sides of the flexor profundis tendons rough, lateral suture of the outer two to the inner two tendons is performed.

Active movements should be encouraged after a week, and after the removal of the stitches, massage, electrical stimulation and active, but not passive, movements should be persevered with.

DESTRUCTION OF THE ULNAR NERVE

This nerve, on account of its subcutaneous position through a large part of its course, is peculiarly liable to injury. When a division has occurred and suturing resorted to, there has been a disappointingly small number of cases in which complete recovery of function has taken place. Various explanations of this poor power of recovery have been advanced. The one which is most commonly accepted is that it is due to the large percentage of afferent fibres in the nerve as compared with such a nerve as the musculo-spiral, which is for the most part composed of efferent fibres growing down from the anterior cornual cells. Whatever the explanation, we know that a large number of cases of injury of the ulnar nerve cannot be rectified by nerve suture, and remain permanently with a complete loss of function in all the parts supplied by that nerve.

The procedure to be adopted depends entirely on the condition of the hand. If there is no stiffness at the metacarpo-phalangeal and inter-phalangeal joints, the hand is extremely useful, and no necessity arises for any active surgical treatment, which cannot correct the small amount of deformity then present.

MULTIPLE NERVE DESTRUCTIONS

There may be complete and irreparable destruction of more than one nerve of the upper limb. For instance, the musculo-spiral and the ulnar nerves may be so completely destroyed that no recovery by nerve surgery is possible. In these circumstances the muscles supplied by the median nerve alone are acting, so that the hand is held fully palmar flexed, and on this account the strength of the active muscles is largely lost. The only tendons which can be spared from the flexor aspect are the pronator radii teres and the flexor carpi radialis. In these circumstances the long arm and half of the transverse portion of the J incision is made as previously described for cases of musculo-spiral paralysis. Through this the pronator radii teres is transplanted as before into the two radial extensors of the wrist, and the flexor carpi radialis is inserted into the extensor ossis metacarpi pollicis, extensor primi and secundi internodii pollicis, and the extensors of the index and middle fingers. By this

means we obtain a hand which can be actively dorsiflexed, and in which the thumb, index, and middle fingers can be fully extended. It will not be necessary in most cases to suture the two functioning outer tendons of the flexor profundus digitorum to the two inner functionless ones, but in a few cases in which there is marked weakness of flexion of the ring and little fingers this procedure will undoubtedly cause considerable improvement in function.

When the median and musculo-spiral nerves are lost, the function which may be obtained is not so good as in the previous circumstances. Here the only active tendon which may be used is the flexor carpi ulnaris. This may be used in one of two ways, either to produce extension of all the fingers by transplantation into their extensors, or it may be used solely to produce dorsiflexion of the wrist by insertion into the dorsal aspect of the base of the fifth metacarpal bone. The function in either of these transplantations is not very good, and in the majority of cases it is preferable to apply a light apparatus which is worn constantly to produce dorsiflexion of the wrist with free finger movements.

DESTRUCTION OF THE MEDIAN AND ULNAR NERVES

After complete loss of function of the median and ulnar nerves it will be found that the patient can voluntarily approximate the tips of the fingers to the palm, and this in many cases leads the surgeon to believe that there is function with completely paralysed muscles. This mistake is due to the fact that the flexor tendons on the anterior aspect of the forearm and fingers when paralysed are as rigid inelastic cords. If the course which they now have to run between their origin from the humerus, and their insertion into the phalanges is increased by dorsiflexion of the wrist, the fingers must be approximated to the palm by the action of the fixed paralysed muscles. If this paralysis of the median and ulnar nerve is irreparable, then the extensor carpi radialis longior is, through a vertical incision along the radial border of the lower part of the forearm, inserted into the flexor longus pollicis, after passing under the tendon of the supinator longus. This gives a thumb which can be voluntarily flexed against a weakly acting row of fingers.

INJURIES OF THE NERVES OF THE LOWER LIMB

Complete Destruction of the Anterior Crural Nerve

This is by no means a common injury. It may occur either intra-abdominally or just as the nerve passes over the brim of the pelvis. Probably the reason why more cases of destruction of this nerve are not seen is because of its situation close to the femoral vessels, so that any

extensive injury to the nerve is likely to be accompanied by other injuries and fatal hæmorrhage. When the function of this nerve has been lost, the gait resembles closely that of a man with an artificial leg which is swinging loosely—he always puts the heel down first with the knee quite straight before venturing body-weight upon it. There is complete loss of power of extension of the leg on the thigh, and if this power is to be regained it must be obtained from the hamstring muscles which are active. There are three of these hamstring muscles which may be safely used. They are the biceps, semitendinosus, and gracilis, and any or all of these may be transplanted and converted into extensors without causing any permanent damage to the power and strength of the leg. The semi-membranosus should never be used as it is so closely associated with the posterior capsule of the knee-joint by means of the strong fascial expansion which it gives to this aspect of the joint. Therefore, the removal of this tendon from its insertion into the tibia is very liable to be followed by a marked recurvatum deformity of the knee, and is quite an unjustifiable surgical procedure.

If it has been determined that no chance remains of producing a functional recovery of a destroyed anterior crural nerve tendon transplantation should be proceeded with. Transplantation of the biceps alone, or in conjunction with the semitendinosus is advisable, as this operation when properly carried out leads to the recovery of the power of voluntary extension of the leg.

A long vertical incision is made over the course of the biceps muscle extending from its insertion into the head of the fibula upwards for a distance of 10 or 12 in. The muscle is dissected out from the surrounding tissue, care being taken not to injure the external popliteal nerve which lies just internal to the muscle along the lower part of its course. The tendon is now divided at its insertion into the fibula and is completely freed from fascia as far up as the origin of the short head of the muscle from the posterior external aspect of the lower end of the femur. The sheath covering the muscle is split to the upper limit of the incision and the muscle thereby freed from restraint, so that its course when transplanted may be an oblique one and not a curve. For the same reason the lower half of the short head of origin of the muscle from the femur is divided (Fig. 128). A small incision about 2½ in. long is now made above the patella, and a wide curved blunt dissector is passed through the superficial fat from the anterior incision to the upper part of the posterior one. The tunnel made by the dissector is enlarged by moving it about freely in the fat, and through this tunnel the tendon is passed from the posterior to the anterior surface of the thigh. Great care must be taken to see that no band of fascia, &c., is holding the muscle, and that the whole course of the transplanted tendon is as far as possible

a straight line so that the muscle may act to the greatest possible advantage.

The sheath in front of the patella is now split vertically and the bone itself exposed. A wedge-shaped piece of bone is removed from the patella with a small chisel, and into this groove the raw-cut tendon of the biceps

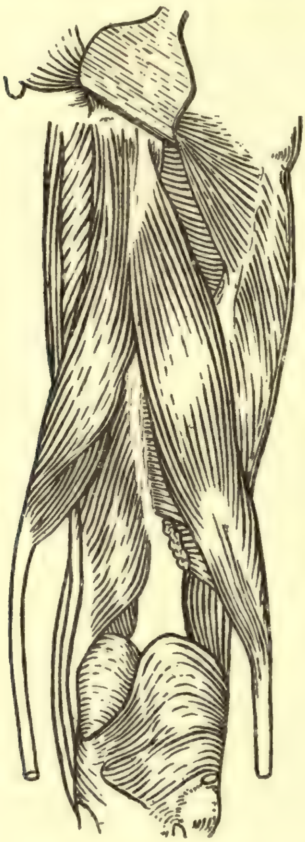


FIG. 128.—Showing biceps femoris and semitendinosus divided close to their insertion.

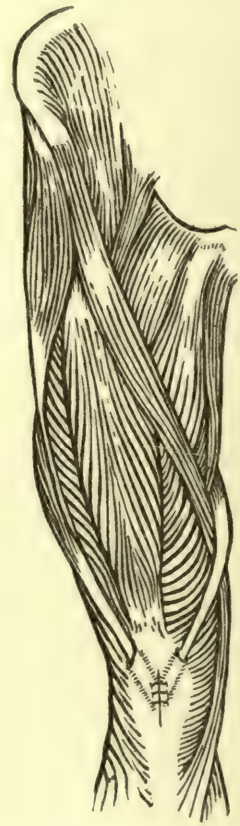


FIG. 129.—Showing biceps and semitendinosus inserted into the patella.

is inserted and fixed by means of sutures of kangaroo tendon or chronic catgut, which pass through both the strong sheath and the substance of the patella itself.

If the biceps tendon alone is used the pull on the patella is a unilateral one and is liable, especially with a tendency to knock-knee, to produce a dislocation of the patella. For that reason, and in order to produce greater power, it is better in all cases to use also the semitendinosus muscle which lies on the postero-internal aspect of the thigh. This

tendon is brought round the inner side of the thigh to the anterior aspect of it in exactly the same manner as the biceps, and is brought into the suprapatellar incision. The wedge-shaped aperture in the patella is made slightly larger and the two transplanted tendons are fixed to the bone under slight tension (Fig. 129). The after-treatment in each case is the same. The knee is kept full extended for a period of six weeks, but massage and electrical treatment of the transplanted muscles is begun as soon as possible after removal of the stitches. Very slight movements of the joint are at first permitted, and the range is gradually increased by active movements.

Destruction of the Great Sciatic Nerve or its Branches

Lesion of these nerves are comparatively common and form about 15 per cent. of all the nerve injuries which present themselves for treatment. Fortunately end-to-end suture of the divided nerve can usually be accomplished after flexion of the knee, which obliterates even a large gap in the nerve tissue. Sometimes, however, this cannot be accomplished on account of the amount of tissue lost, or because ankylosis of the knee-joint has occurred. Some other method of treatment is therefore necessary to restore function. The great desideratum of tendon transplantations and fixations in the leg is stability, as previously stated, in contradistinction from those of the upper limb, where the goal to be sought is active movement.

Destruction of the External Popliteal Nerve

When this nerve has been destroyed the foot hangs permanently in a position of plantar flexion with a slight varus deformity.

There is a complete paralysis of all the muscles on the anterior aspect of the leg and of the two peronei muscles. Transplantations of the whole or part of any of the acting tendons on the posterior aspect of the limb have not been successful in producing the active movement which was desired. But tendon fixation for this condition has proved much more successful.

The object of tendon fixation here is the obliteration of the paralytic drop-foot, so that the foot may be maintained during walking in dorsiflexion, and can never again fall into the distressing condition in which the foot is dragged along the ground with marked discomfort and loss of stability to the patient. This fixation of the foot in the right-angled position has been produced by performing an arthrodesis of the ankle-joint in the desired position, but this only relieves the drop-foot by causing a crippling rigidity of the foot, which the patient may consider to be worse than the original deformity.

There are three muscles which are usually used for tendon fixation.

These are the tibialis anticus, peroneus longus, and the peroneus brevis. The only other tendon which might be used is the peroneus tertius, which produces eversion and dorsiflexion, but is extremely weak and very liable to stretch with use. When the peroneus longus is pulled upon in its position behind the fibula it produces marked eversion of the foot combined with plantar flexion especially of the inner border of the foot, which is also pulled down to a position of 30° below a right angle. If the peroneus longus tendon is transplanted to the anterior aspect of the fibula and pulled upon, it produces the same action, but the plantar flexion is now only to an angle of about 15°. If the peroneus brevis tendon is tightened when in position behind the fibula, the foot takes the position of eversion, and plantar flexion to an angle of 25°, whilst tension on this tendon after it has been transplanted to the anterior aspect of the leg pulls the foot into a position of eversion at right angles.

A vertical incision is made along the outer aspect of the anterior edge of the tibia from a point 2 in. above the ankle-joint and extending upwards parallel to the bone for a distance of 4 in. This incision lies directly over the tibialis anticus tendon, which is seen on dividing the strong sheath covering it and holding it to the tibia. The tibialis anticus tendon is now divided at the upper end of this incision. A vertical incision 2 in. in length is now made ½ in. behind and parallel to the fibula from a point 4 or 5 in. above the ankle-joint. Through this incision the tendon of the peroneus brevis is divided (Fig. 130). Another incision 1 in. in length is made over the course of the peroneus brevis tendon just behind its insertion into the base of the fifth metatarsal bone. An elevator is now passed through this lower incision under the cut tendon, and the divided portion of the tendon then pulled out through this opening on to the surface of the foot. A long dissector is passed down from the incision over the tibialis anticus, and the divided peroneus brevis tendon is pulled through to this upper incision underneath the anterior annular ligament.

The periosteum of the tibia opposite the lower part of this incision is divided, and a hole drilled horizontally through the bone. The lower portions of the divided tendons of the peroneus brevis and tibialis anticus muscles are passed through it (Fig. 131). These tendons are fixed so that they retain the foot in a position of dorsiflexion of 15° above the right angle, and the foot is immobilized in plaster of Paris in this position for a period of eight weeks; during the second four weeks the patient can walk about freely in the plaster.

Destruction of the Internal Popliteal Nerve

In this condition the action of gravity so helps to obscure the paralysis that careful inspection is usually required before it can be definitely ascertained that any loss of function is present in the limb. The only sign

is a marked loss of spring in the foot, and the gait is that seen in the case of a decided flat foot, so that the whole sole of the foot is placed on the ground at once, thus obliterating altogether the normal heel and toe action. This condition may be treated as follows.

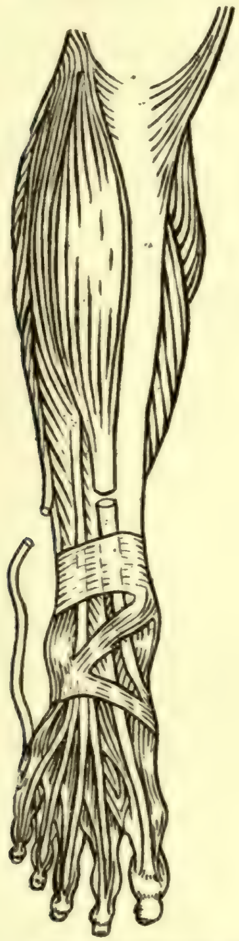


FIG. 130.—Showing peroneus brevis divided and brought clear of the annular ligament, and tibialis anticus divided and left in position.

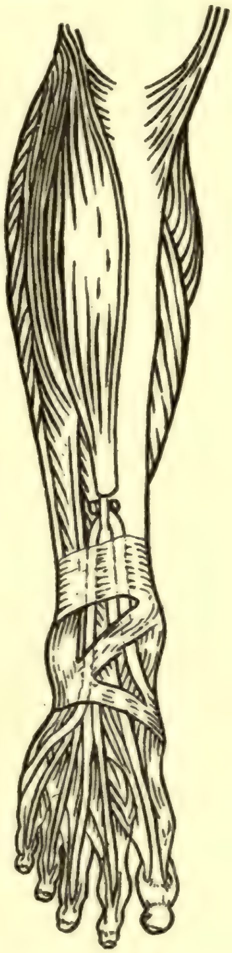


FIG. 131.—Showing peroneus brevis and tibialis anticus placed through a hole in the tibia.

A vertical incision is made along the outer border of the tendo Achillis extending upwards for $3\frac{1}{2}$ in. from a point an inch and a half above its insertion. Through the whole length of this incision the tendon is split longitudinally into two equal portions and a transverse incision is made through the outer half of the split tendon at the upper limit of the incision. A large 'through and through' opening is made through

the posterior surface of the tibia about the level of the middle of the incision. The divided upper end of the lower portion of the split tendo Achillis is threaded through this opening and pulled until the requisite tension has been obtained when it is sutured back on itself, close to where it was introduced through the bone, the tension being maintained during this procedure.

When both the internal and external popliteal portions of the great sciatic nerve are destroyed both these operations are performed and the foot tightly fixed at an angle of 80° with the leg. It is fixed in this position for a period of eight weeks, after which it may be freely used without any fear of stretching of the implanted tendons.

INJURIES OF THE HEAD

BY

COLONEL E. FARQUHAR BUZZARD

AND

LIEUT.-COLONEL PERCY SARGENT, D.S.O., C.M.G.

INJURIES OF THE HEAD

INTRODUCTION

All gunshot wounds of the head should be regarded primarily as injuries of the brain accompanied by more or less damage to the scalp and skull. In the earliest stages it is the actual wound, with its lacerated scalp, its splintered bone, and often its extruded brain matter, which naturally arrests the attention ; only the most gross and obvious evidences of cerebral injury, such as loss of consciousness and paralysis, may be noted. The chief problem at this stage is that of getting the wound to heal speedily and, if possible, aseptically. Later, if aseptic healing fails, the wound is still in the foreground of the clinical picture, and the prevention and treatment of septic complications constitute the surgeon's primary task. But later still, when the wound is healed, these cases afford, except for an occasional instance of recrudescence of a latent infection, little scope for active or dramatic surgery ; they present problems which come more clearly within the province of the neurologist and of those concerned with the care of the disabled.

The victims of head wounds may be disabled in a large variety of ways including defects of mind, motion, common sensibility, and of the special senses. The consideration of many of these defects hardly comes within the scope of this article, but all disabilities affecting the proper use of the limbs, their recognition and treatment, are matters of interest to physicians and surgeons whose duty it is to restore the disabled soldier to the highest possible degree of usefulness and activity. Participation in a great war lasting several years means that the medical profession of the country must become only too familiar with patients suffering from cerebral injuries, and it is not too much to expect that it should be prepared not only to treat the paralyses and other direct results of such injuries, but to recognize and deal with the complications and remote consequences which must inevitably arise in a certain proportion of cases. For this reason we cannot be content to discuss the diagnosis and treatment of simple destructive lesions only, but must consider briefly such subjects as brain abscess, encephalitis, the presence of foreign bodies, and traumatic epilepsy. None of these troubles is peculiar to warfare, although their incidence in peace time is so infrequent as to make them remarkable and therefore not so well understood, perhaps, as they might be. We might go further and point out that the

ordinary hemiplegia of vascular origin has not in the past received the attention it deserves from the remedial point of view, and that, if any good can be attributed to this disastrous war and its long account of suffering, it may be found in a wider understanding of the common tragedies of life and their appropriate treatment.

CRANIO-CEREBRAL TOPOGRAPHY

In gunshot wounds of the head, the site of the chief injury is usually sufficiently obvious, and the radiographic examination and primary 'cleansing' operation can ascertain with a fair degree of accuracy the amount of the gross damage. But the true extent of the cerebral injury can only be determined by neurological examination, and that only when the general or local concussion effects have passed off. A deeply penetrating missile, or a contrecoup contusion will give rise to symptoms not referable to that part of the brain underlying the cranial wound, whilst wounds which appear to be very similar in extent and degree may, in the same situation, be associated with widely different degrees of cerebral injury, as evidenced by neurological examination. A comparison of the visual fields in a number of cases of occipital injury, for example, shows how little the extent of the cerebral lesion can be ascertained from an examination of the cranial wound.

For practical purposes the more complicated systems of cranio-cerebral topography, such as are used in anthropology, are not necessary and the simplest methods will suffice. The *nasion* is that point at the root of the nose where the nasal bones join the frontal, and the suture can usually be felt distinctly. The *inion*, or external occipital protuberance, can readily be felt in the midline behind, slightly above the level of the auditory meatus. The *pterion* is situated at a point $1\frac{1}{2}$ in. behind the external angular process of the frontal bone, and 2 in. above the zygoma.[1] From these three points the chief cerebral areas can be mapped out. The pterion corresponds with the point at which the sylvian fissure appears upon the external aspect of the brain, and the first $3\frac{1}{2}$ in. of a line drawn from this to a point a hand's breadth above the inion corresponds with the sylvian fissure. The rolandic fissure is represented by a line drawn for $3\frac{1}{2}$ in. downwards and forwards from a point $\frac{1}{2}$ in. behind the mid-point between nasion and inion, at an angle of 67° with the sagittal line. This angle is readily found by Chiene's method, i.e. first fold a rectangular piece of paper so as to bisect one of its angles, and then fold it again so as to divide each of the angles of 45° into two :

[1] See Fig. 1, p. 2, Rawling's *Surgery of the Skull and Brain*, Oxford Medical Publications.

on opening out the folded paper, we have four angles, each a quarter of a right angle; three of them together give an angle of 67·5°. From these two principal fissures the position of the other main sulci can be marked out.

The position of the ventricles must be remembered in dealing with cerebral wounds. The position in relation to an X-ray picture of the skull is shown in Fig. 132.

The situation of the chief blood sinuses is also important. The line of the lateral sinus runs from the inion to a point 1 in. behind the external

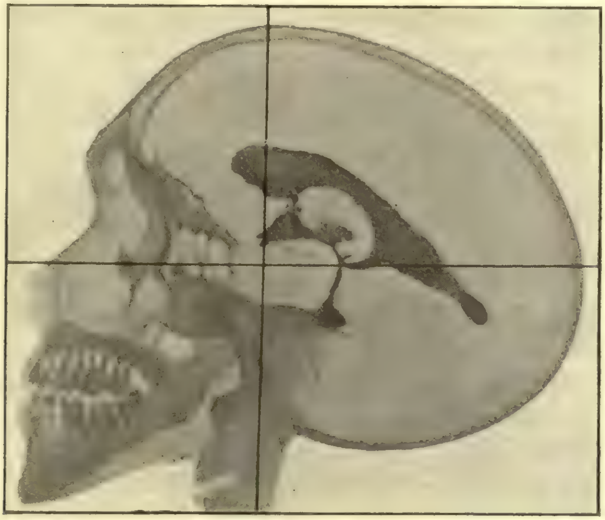


FIG. 132.—From an X-ray photograph, by H. E. Gamlen, illustrating the position of the ventricles in relation to the surface of the skull. The ventricles have been filled with bismuth.

auditory meatus; that of the longitudinal sinus follows the mid-line from nasion to inion. The longitudinal sinus receives the cortical veins into lateral expansions or lacunæ, which vary greatly in extent, but are fairly constant in position. Of these the chief is the *parietal lacuna* situated at, or slightly in front of, the mid-point of the vertex, and receiving the large post-central, and the smaller pre-central and rolandic veins. The chief interest of this parietal lacuna is its relation to wounds of the vertex associated with the symptom-complex known as the longitudinal sinus syndrome.[1] Below the line of the lateral sinus lies the cerebellar fossa, thickly covered by the mass of cervical muscles.

[1] See 'Injuries of the Superior Longitudinal Sinus', Holmes and Sargent, *B.M.J.*, Oct. 2, 1915.

EARLY SURGICAL TREATMENT

With the cessation of hostilities, problems of early treatment have receded into the background. A few words, however, may not be out of place in view of the tendency, so often encountered, to question whether a different line of treatment in the earliest stage of the injury would have been followed by a better result.

The disabilities which result from these wounds are due to derangement of cerebral function consequent upon lesions produced either directly and immediately by the injury, or secondarily by microbic action. A further series of symptoms may result from cicatricial lesions or from other secondary changes not dependent upon infection.

The aim of treatment in the earliest stages is primarily to eradicate infection and to secure as rapid and reactionless healing of the wound as possible. It is now generally believed that an early and thorough operation, directed to the cleansing of the wound, with primary closure, affords the best means of attaining rapid healing, and consequently of avoiding those complications and sequelæ which result from sepsis. It was, in fact, to cranio-cerebral wounds that the principle of excision and primary suture was first applied. The comparatively bad results in the early days of the war were not due so much to faulty principles and technique as to the fact that the military situation rendered it impossible to deal thoroughly with these cases sufficiently soon after the infliction of the wound. But whilst the operator seeks to obtain aseptic healing, he must at the same time bear in mind that disorders of cerebral function, often permanent, also arise from the initial injury, and that any rough handling may increase the ultimate disabilities.

There is a somewhat widespread impression that the early symptoms due to cerebral injury can be directly benefited by surgical means. The evidences upon which such a view is based are scanty, and the error is attributable to one or both of the following reasons: firstly, lack of neurological examination, or to misinterpretation of such signs as may have been elicited before operation; and, secondly, to a lack of appreciation of the nature of the cerebral lesion.

To sum up, there is plenty of evidence that an early and thorough cleansing operation affords the best means of avoiding septic complications, but there is little or no evidence that surgical interference can relieve the symptoms due to the cerebral injury. An exception must be made of the cases of progressive sub-dural hæmorrhage, but this is a rare event in gunshot wounds.

The further question arises, however, as to whether anything can be done at the primary operation to prevent or minimize such sequelæ, other than the infective complications, as may arise at a later period.

The most important of these are epilepsy, headache, neurasthenia, and insanity. We may dismiss the last two, which few could be found to assert were preventable or remediable by surgery, and consider only headache and epilepsy, the former being a common cause of long continued disability, and the latter a comparatively rare one. The causation and treatment of headaches will be considered later, but it may be said here that they occur in patients with every variety of cranio-cerebral wound, and we know of no ground for believing that any operative measures in the early stage could influence their occurrence. With regard to epilepsy, it is a traditional belief that the presence of depressed or indriven bone, and of metallic foreign bodies, produces fits, and that therefore primary operative measures should be directed to removing these sources of irritation. Epilepsy occurs in patients both with and without cranial defects ; with and without depressed fracture, bony spicules, and foreign bodies ; whether an operation has been performed or not. Whatever may be the influence of these various factors upon the causation of traumatic epilepsy, it is at least certain that their presence does not necessarily produce it, neither does their early removal avoid it, nor their late removal cure it.

PATHOLOGY

We have to consider the pathological anatomy firstly in cases uncomplicated by septic infection. Nerve cells and fibres are either definitely and finally destroyed ; or they are temporarily thrown out of action by concussion, by the presence of small hæmorrhages, or by œdema. In the first case no recovery is possible, for no regeneration occurs in the central nervous system ; in the second event recovery of function is possible. Concussion effects, as shown by the neurological signs, are both general and local. General concussion, followed by loss of consciousness, muscular flaccidity, and so on, is commonplace enough even in civilian practice ; but local concussion effects are not so generally recognized, though they are very definitely present in large numbers of cases of gunshot wound of the head.

The gross naked-eye lesions presented by severely injured brain are familiar to all who have seen even a few gunshot wounds of the head ; they have somewhat aptly been summed up in the expression ' pulped brain '.

From the point of view of septic sequelæ almost everything depends upon whether or not the dura remains intact, that is to say unperforated either by the missile, by fragments of bone, or by meddlesome surgery. It is true that occasionally cerebral infection arises where there has been no obvious perforation, but such cases are very rare, and it is in general terms true to say that a whole dura mater means recovery.

In one series of cases, for example, the mortality with unperforated dura was less than 6 per cent., but with perforated dura 41 per cent. (Adie and Wagstaffe); in another (Kennedy and Walker, personal communication) the relative mortality was 8 per cent. and 46·5 per cent.; and in a third (Sargent and Smith) it was 3·3 per cent. and 41·3 per cent.

But from the functional point of view, the importance of the integrity of the dura is harder to estimate; for, generally speaking, wounds which penetrate this membrane are more severe than those which do not. This might be held to account, in part at least, for the greater mortality in cranio-cerebral wounds with dural perforation, but the fallacy of such an argument is shown by the fact that almost all the deaths in that group are due to septic infection.

The idea that 'pulped brain' underlying a non-penetrating cranial wound is likely to be a source of future troubles has led some surgeons to advocate its removal through an incision or puncture of the dura, when that membrane, exposed by a trephine opening and unpenetrated by the original injury, fails to exhibit visible pulsation.

Such a procedure may relieve intra-cranial pressure, which can be done by lumbar puncture; it also carries with it a very real risk of introducing bacteria and producing abscess, encephalitis, and meningitis. In a series of 105 cases with intact dura operated upon (Sargent and Holmes), 95 had the dura left intact and all were evacuated to England improving; 10 had the intact dura incised, and of these 3 died, whilst 2 others developed fungus cerebri with complete hemiplegia, one of them being rendered aphasic. Cushing had one death from sepsis in 11 cases in which the intact dura was incised. Sidney Smith operated on 16 cases with intact dura; 4 out of the 5 in which he incised the dura died, whilst 10 of the remainder recovered, the one death being due to tetanus.

But the aspect of this operation with which we are here concerned is whether or not it does or can influence subsequent disabilities, more especially those which arise from permanent disorders of cerebral function such as paralysis, aphasia, visual disturbances or other disorders of a more functional type, such as headache, neurasthenia, insanity, and epilepsy. Neither does a consideration of the morbid anatomy of the cerebral lesion lead us to suppose that surgical interference with 'pulped brain' would be likely to avert any of the subsequent disabilities, nor are we aware of any clinical evidence that patients whose 'pulped brain' has been evacuated are any better off than others. If it were so, then penetration of the dura by the original injury would, if intra-cranial sepsis were avoided, be an advantage, as it allows of the immediate escape of 'pulped brain'.

REGIONAL SYMPTOMATOLOGY AND TREATMENT

The neurological investigation of head injuries is of importance not only from an academic point of view, but from that of treatment. Further, it is only possible by the repetition of such examinations and the comparison of their results that an accurate estimate of the progress made by the patient can be appreciated, and the development of complications such as haemorrhage, abscess and encephalitis can be detected. An alteration in the patient's general condition and the supervention of drowsiness, vomiting, headache, optic neuritis, slow pulse, and other symptoms may give rise to the suspicion that all is not going well, but the localization of the trouble must depend on the appearance or modification of neurological signs.

Before discussing the symptomatology and treatment of head injuries in relation to their various sites it is desirable to draw attention to one or two principles which should be observed in the care of all patients who come into hospital suffering from more or less severe damage to the brain.

When a brain has been injured the first duty of the surgeon is to satisfy himself that the local pathological condition dependent on the injury is rendered as favourable for repair and as unfavourable for complications as he can make it. Having secured this his second duty is to give the brain every chance of recovering its normal function or as much of that function as is possible. There can be little doubt that complete mental and physical rest for a prolonged period is the first necessity in order to attain the end in view, and we hold the opinion that in all head injuries where there is evidence that the brain has been involved, either by bruising or laceration, at least a month's complete rest in bed, and often a much longer time, should be prescribed. This measure needs all the more insistence because the patient is often restless and anxious to get up long before he is really fit to do so. It should be the general rule, therefore, not only to enforce the rest, but to administer a daily dose of 20 or 30 grains of bromide to every patient for some weeks and even months after his injury. Our experience teaches us that this line of treatment goes far to prevent the development of the troublesome sequelæ of head injuries in the shape of headaches, insomnia, giddiness, depression, exhaustion, irritability, and other neurasthenic symptoms, and probably exercises a favourable prophylactic influence against traumatic epilepsy.

The adoption of these measures in no way interferes with the early treatment of disabilities, the prevention of contractures, and the correction of unfavourable postures on the lines presently to be described.

WOUNDS OF THE PRE-FRONTAL REGION

Symptomatology. Wounds of this area are not associated with remarkable physical signs from a neurological point of view, but close investigation of the patient's mental condition, especially when the results are compared with what is known of his previous character, frequently reveals the fact that a psychic alteration has taken place. There is often a certain degree of mental torpor or apathy, a change in the mental outlook, or a deterioration in the patient's sense of responsibility, sense of perspective, initiation, and manners. Associated with these features there is not uncommonly a history of vesical or fæcal incontinence due rather to tardiness in attending to the earlier calls of nature than to complete loss of control, and sometimes accompanied by a deficient appreciation of the offence.

Complications are frequent. Vision may be impaired either by injury to the optic nerve, or by concussion effects on the eyeball, leading to choroido-retinal or macular lesions. The sense of smell may be diminished or abolished owing to damage to the olfactory lobe. Frontal sinus suppuration is a troublesome sequela and may lead to more deeply seated abscesses.

Treatment. No active measures are indicated from the medical point of view, but the absence of paralyses or other obvious disabilities should not tempt the medical officer to neglect giving the patient at least a month's rest in bed and a long period of convalescence. The prospect of recovery in regard to the mental condition and incontinence is generally favourable, although the ability to resume the ordinary duties and responsibilities of life with success may be long delayed and in some cases destroyed.

WOUNDS OF THE PRE-CENTRAL REGION

Symptomatology. Paralysis is the chief feature of wounds of the precentral region of the brain, and the picture of hemiplegia, more or less complete, is that with which we are confronted when the patient reaches hospital. Whether the paralysis remains general, or whether it gradually limits itself to the leg, arm, or face, will depend on the depth and site of the injury; and whether anarthria or dysarthria, associated with some degree of aphasia, persists will depend on the site of the lesion.

The paralysis at first is flaccid, with abolition of all reflexes, but sooner or later there will develop an increase of tone in the affected limb or limbs which is accompanied by the usual hemiplegic reflexes and by the adoption of certain well-known limb postures.

If the injury to brain tissue is limited to the ascending frontal convolution sensory defects are not conspicuous, but some impairment of sense of position and movement and some deterioration in the ability

to appreciate differences in the weight and form of objects, to discriminate (compass test) and to localize are sure to be found on close investigation. Although not obvious on superficial examination, nevertheless these defects contribute to the patient's disability, and even when much of the initial paralysis has disappeared help to impede the usefulness of a limb.

Treatment. It cannot be too often or too firmly insisted upon that the treatment of hemiplegia should be begun as early as possible after the shock of the injury has passed off and as soon as the general condition of the patient permits. The medical officer in charge should invoke the assistance and co-operation both of the nurse and of the patient, and to each he should explain that the recovery of useful power in a paralysed limb will depend largely upon two factors. In the first place, and this is the chief concern of the nurse, the helpless limb must be prevented from assuming a fixed position and developing arthritic adhesions or muscular contractures. In the second place, the patient must be made to understand that return of movement is not going to be brought about by massage or electrical treatment, but by his own efforts, that there is nothing amiss with the arm or leg, and that his participation in the treatment is essential for re-establishing communication between his damaged brain and his healthy limbs.

The practical application of these two principles may be described with advantage in greater detail. In the upper paralysed limb there will develop in most cases a natural inclination towards adduction at the shoulder, flexion and pronation at the elbow, and flexion of the wrist and fingers. In the lower limb there will be found a tendency to extension at the hip, extension of the knee, and extended inversion of the foot. These tendencies must be thwarted by frequent changes of position and by such simple mechanical means as pillows, sandbags, and the temporary application of splints. But *change* of position should be the object aimed at ; harm may be done by over-splinting as well as by neglect.

As soon as the patient begins to recover some voluntary power his assistance should be invoked. He must be told not to lie continually in bed with his arm folded across his chest. He must be asked to place it from time to time fully extended and supinated away from his body.

At this stage another piece of advice must be offered. With the recovery of a certain movement the patient will naturally incline to devote all his energies towards developing that movement. This should be discouraged and he should be asked to give more of his time and his energy to regaining the antagonistic movement and movements at other joints. Tell the patient to go systematically over each movement at each joint two or three times every day and to make the mental effort

to reproduce them whether success attends the effort or not. In this way the first appearance of a new movement will be watched for and welcomed with the result that the patient's interest is stimulated and his co-operation assured.

Good advice is also required when he begins to walk. His natural inclination will be to walk in the fashion which comes easiest to him, advancing his leg by circumduction and neglecting to flex his hip or knee. From the first he should be encouraged to try and walk in as normal a manner as possible and not to follow the path of least resistance. Unless these precautions are taken ungainly positions and ugly movements will become more of a habit than a necessity.

Massage and passive movements are useful adjuncts to the above-mentioned measures in the treatment of paralysis due to lesions of the upper motor neurons, but the success of the rubber depends largely upon how far she or he secures the interest and active participation of the patient in his treatment.

Inasmuch as the nutrition and functional activity of the muscles are rarely affected the use of electricity is not often indicated, and its general use in cases of hemiplegia is to be discouraged on account of its tendency to increase reflex-spasm.

In a certain number of instances all remedial efforts will fail to bring about a useful recovery of function in a limb or to prevent the development of crippling contractures. Operations for dividing or lengthening tendons and even for bringing about temporary peripheral nerve palsies may possibly have their use. When the use of the hand is impeded by strong flexor spasms of the fingers, while some power of extending the latter is retained, it may be justifiable to throw the flexor muscles temporarily out of action by injecting the median nerve with 70 per cent. or 80 per cent. alcohol. The possible risk of causing permanent loss of sensibility in the hand and fingers has, however, to be taken into consideration and suitable appliances giving the extensors mechanical help may be preferred.

In dealing with these cerebral disabilities the surgeon must not be guided by the same principles as those he adopts in cases of paralysis due to lesions of the peripheral nerves. For instance, a hemiplegic patient may be quite unable to dorsiflex his ankle with the knee in the extended position, but may be able to perform this movement when the knee is flexed. In walking, therefore, he may pick his toes off the ground when he flexes his knee and an apparatus which he wears for drop-foot becomes quite superfluous. It is well to bear in mind that in cortical lesions we are confronted by the inability to perform certain movements and not by paralysis of individual muscles.

WOUNDS OF THE POST-CENTRAL REGION

Symptomatology. Injuries inflicted on the post-central cortex are usually attended at first by some degree of motor paralysis, but the latter tends to clear up, leaving the severe disabilities resulting from defective sensibility in the limbs of the opposite side. As in the case of the pre-central traumata the disturbances may affect the whole of the opposite side of the body or may be limited to one limb or even to a small area on one limb. The most serious disability obtains when the arm and hand are affected. If the lesion is a cortical one there may be but slight deterioration in the patient's appreciation of tactile, painful, and thermal stimuli although he may describe them as unnatural and be unable to localize accurately their origin. On the other hand, he will display profound defects in his sense of position and movement, in his recognition of the size, shape, and weight of objects, in his discrimination of compass points, in his sensibility to the vibration of a tuning-fork, and in his power of localizing all stimuli.

Such a patient presents an unusual picture and one which may easily give rise to errors of diagnosis. He can carry out all movements with power and can appreciate touches and pin-pricks, but complains that the limb is almost useless, that he cannot button his clothes, cannot write, cannot pick out coins from his pocket, and that he is always letting things slip from his grasp unless he keeps his eyes and attention fixed on his hand.

If the lower limb is affected the disability is not so great, but it will be sufficient to make him uncertain on his feet and liable to stumble against steps or other obstacles unless he walks with great care.

In the case of patients where there has been great destruction of cortical and sub-cortical tissue the picture is changed by the addition of certain modifications in regard to painful and thermal sensibility. The threshold for the perception of these stimuli is raised, but when perceived the resulting discomfort is much exaggerated. A light scratch on the palm of the hand or the sole of the foot may give rise to great suffering, and the unfortunate victims of this type of cerebral lesion often experience paroxysms of spontaneous pain which resist all forms of treatment.

Treatment. The re-education of sensory function is a task which the patient must be expected to take upon himself. To some extent it comes naturally as he will doubtless attempt, involuntarily, to make use of a hand which he can move, and in that way try to bring it under control. But this recovery will be more rapid and more perfect if he is taught to spend a certain amount of time every day in carrying out actions destined to re-educate his sensibility. He can, for instance, make the attempt to place his fore-finger on different parts of his anatomy with his eyes closed

until he has arrived at some degree of accuracy. He can practise his sense of size and form by trying to recognize and pick out objects of various kinds from a collection placed before him without bringing his visual powers to his assistance. Measures adapted to this purpose can be multiplied, with the result that persistent daily practice will make perfect, or as near perfect as the damage to the cortex will allow. All efforts at restoring sensibility by means of massage or passive movements or electricity can have little or no reasonable basis, but the system of re-education generally known as Fraenkel's exercises can be used with advantage.

WOUNDS OF THE VERTEX

Warfare has brought into prominence a clinical picture, almost unknown in peace, due to the frequency of injuries to the vertex of the skull and to the subjacent superior longitudinal sinus. Gutter fractures with depressed bone and other traumata in this region give rise to immediate paralysis which may affect all four limbs, one arm and both legs, or both legs only. As a general rule the arms recover rapidly and the patient is left with a cerebral paraplegia which may be of spastic or ataxic type according to whether the injury is inflicted more anteriorly or more posteriorly. In other words the disability of the lower limbs may be due either to spastic paralysis with the usual reflexes associated with that condition, or to sensory disturbances causing ataxy as the most prominent symptom. In many instances the picture is a mixture of both conditions.

Treatment. The disabilities attendant upon injuries to the superior longitudinal sinus are really the result of bruising and interference with the circulation of the neighbouring cortex, and require treatment on the same principles as those which apply to cases of injury to the pre-central and post-central cortex. It is desirable that the medical officer should determine in each instance how much of the difficulty in walking is attributable to loss of voluntary power and how much to interference with the afferent impulses from the muscles, tendons, and bones of the affected limbs. He will then be able to direct the re-education on appropriate lines.

WOUNDS OF THE CEREBELLUM

Symptomatology. In the majority of cases of injury of the cerebellum the chief incidence of the lesion is found to be on one or other lobe, and the disability resulting from this lesion affects predominantly the limbs on the same side of the body, although the opposite limbs may be affected in a less degree.

The disturbance of cerebellar function is demonstrated by disorders of voluntary and automatic movement, and by the assumption of

abnormal positions and attitudes. These symptoms have been studied in detail by Babinski, Gordon Holmes,[1] and other observers, but it will suffice to describe here the more important factors which give rise to disablement in the patient.

In the first place the affected limbs show a certain degree of loss of tone. They are flaccid and flail-like and oppose little or no resistance to passive movement even when the joints are flexed or extended beyond the usual limits. This loss of tone can be demonstrated in various ways. If the patient is asked to flex his elbow strongly against the resistance of the observer who holds his wrist, and the latter suddenly lets go, the hand will be jerked towards the shoulder further than it would be with a normal subject. Similarly in testing the knee jerk when the leg is hanging unsupported on the edge of a chair the initial jerk will be followed by several oscillations before the limb is finally brought to rest.

Atonia is closely associated with some degree of paresis. The hand grasp is noticeable for diminution of strength and for irregularity in the maintenance of what power it displays. There is delay in initiating the muscular contractions and delay in reaching their maximum power. There is a similar delay in initiating and reaching the condition of relaxation. This disability is well brought out by asking the patient to perform some movement followed by its opposite in rapid succession. Thus the attempt to pronate and supinate the forearm quickly may be carried out with great awkwardness, and the physical sign known under the name of 'dysdiadochokinesia' (or 'difficulty in performing repeated movements') may be demonstrated.

In the next place attention may be drawn to the asynergia in carrying out voluntary movements. There is a lack of co-operation between agonist muscles and their antagonists and between agonist muscles and their synergic muscles. This disorder leads to disturbances of gait and stance and to disability in performing more or less complicated movements requiring the co-ordinated action of various groups of muscles. When the patient, lying flat on his back with his arms folded across his chest, is asked to sit up the attempt will be handicapped by his legs rising, owing to his inability to keep them fixed while contracting his abdominal muscles. In walking there may be seen overaction (hypermetria) with the result that the leg is over-extended at the knee and the foot brought clumsily and forcibly to the ground.

Disturbances of balance with or without symptoms of vertigo are frequently met with, and there is a general tendency on the part of the patient to sway or fall to the side of the lesion or to deviate in his walk in a similar direction. These signs and symptoms associated with

[1] See *Brain*, vol. xl, p. 461, Dec. 1917.

nystagmus and unaccompanied by any important alteration in the reflexes are characteristic of cerebellar lesions.

Treatment. Time and re-education are the only important factors in the treatment of cerebellar disabilities, and on the whole they are wonderfully successful. In the case of severe injuries a certain amount of clumsiness of movement may be left as a permanent defect.

RESULTS OF CRANIO-CEREBRAL INJURIES

Although figures are available from many sources, it is difficult to come to any very clear conclusions as to the results. There is no uniformity in the methods of setting out results, whilst much confusion exists as to the classification of the different types of injury. Standards of recovery naturally vary with different observers, and the dates at which the observations are made are not always clearly set out. Further, the more remote after-effects cannot be estimated for years to come. Nevertheless, the material at our disposal is very valuable as it stands, and it is possible to deduce a number of important points from a study of it. Some British, French, and German statistics may be briefly quoted :

(1) *Sargent and Holmes*, 1916.

1,239 cases—traced after evacuation to England :

Approximately 0·6 per cent. insane.
6·0 ,, fits.
1·2 ,, abscess.
3·7 ,, dead.

69 cases with metallic foreign body retained :

4 per cent. dead.
76 ,, wounds soundly healed.
30 ,, completely recovered—no cerebral symptoms.
40 ,, neurological symptoms much improved.
10·5 ,, much disability persisted.

(2) *Tuffier and Guillain*, 1917.

6,664 cases :

Approximately 0·6 per cent. insane.
10·0 ,, fits.
1·4 ,, abscess.
27·5 ,, gross neurological signs.

(3) *Roeper* (*Deutsche Med. Woch.*), 1918 :

20 per cent. dead since discharge from hospital.
34 ,, incapable of any employment.
34 ,, capable of some work.
12 ,, free from gross disability.

Goldstein (800 cases):

16	per cent.	incapable of any employment.
32	,,	capable of light employment.
32	,,	capable of their former employment.
20	,,	'not grossly affected'.

CEREBRAL ABSCESS

The following statistics sufficiently well indicate the percentage of cerebral abscesses which may be expected:

Tuffier and Guillain in 6,664 cases	. .	1·41 per cent.
Adie and Wagstaffe in 656 ,,	. .	2·1 ,,
Sargent and Holmes in 1,239 ,,	. .	0·97 ,,
Holmes in 2,357 ,,	. .	1·1 ,,

The comparatively high percentage in the second series is accounted for by the fact that all were early cases. The chance of abscess formation becomes progressively less with lapse of time.

In Holmes's series 28 out of 37 cases occurred within six months, 4 between six and seven months, 3 between eight and nine months, one after ten months, and one after eighteen months. Eight of the 37 cases recovered after operation.

As a rule, the symptoms of abscess are of slow onset. Occasionally none are noted before sudden death owing to the bursting of the abscess into the ventricle.

The symptoms may be grouped as follows:

1. Those of a general character, including progressive wasting, anorexia, asthenia, and irregular pyrexia.
2. Those due to increased intra-cranial pressure, namely, headache, vomiting, giddiness, slow pulse, and papillœdema. Drowsiness and apathy are often prominent signs.
3. Those referable to interference with the function of that part of the brain in which the abscess is situated. Thus in the occipital region a partial visual defect due to the original injury may become a complete hemianopia; an old hemiparesis may become more pronounced; reflexes may undergo alteration; defects of speech may be noted; and mental symptoms may appear. The cerebro-spinal fluid will be found under increased tension, whilst its cell and albumen content will be abnormally high.

When any considerable number of these symptoms present themselves at the same time, the diagnosis is easy. But many cases fail to exhibit any very characteristic clinical picture; indeed, now and then a patient,

apparently quite well and going about, becomes suddenly unconscious and dies in a few minutes from the rupture of an unsuspected abscess. In our experience any signs of unusual quietude, of lethargy, indifference to surrounding events, or somnolence, in a patient with a gunshot wound of the head of a few weeks' duration, especially if the wound be not quite healed, should arouse suspicion as to the possibility of abscess, and should lead to detailed and repeated neurological examination.

Between an encapsuled abscess and a diffuse encephalitis, inflammatory lesions of all grades are met with as the result of the implantation of microbes along the track of a cerebral wound. It is not always possible to distinguish clinically between abscess and encephalitis ; indeed, a more or less localized collection of pus may be surrounded by an area of spreading inflammatory softening. The diffuse encephalitis is usually of earlier origin and more rapid development, and the symptoms due to toxæmia and to increased intracranial pressure are more insistent than the localizing signs.

Treatment of Cerebral Abscess. Free drainage directly a diagnosis has been arrived at offers a reasonable prospect of recovery. An attempt should be made to reach the abscess along the track of the original wound rather than through a separate opening. Unfortunately, these abscesses often have diverticula leading from them into secondary abscesses : and again, they are apt to be surrounded by an area of diffuse spreading encephalitis. It is to these unavoidable accidents that want of success is usually due.

HERNIA CEREBRI

Hernia, or more properly ' fungus ' cerebri, is an indication of raised intracranial tension, and can only occur when, in addition to the increased intracranial pressure, there exists a defect both in the dura mater and in the bone. It is usually seen protruding through an unhealed wound in the scalp, but occasionally occurs beneath a healed scalp. Such a fungus is merely evidence of increased intracranial pressure, which, again, depends upon cerebral or meningeal inflammation. Withdrawal of cerebro-spinal fluid by lumbar puncture results in a diminution in size, or at least in tension, of the fungus.

Treatment of Fungus Cerebri. Any increase in the size or tension of a fungus may be one of the evidences of the formation of an abscess to which, therefore, treatment has to be directed. In the absence of such evidence of abscess formation, no active treatment is required, and the fungus will, in most cases, gradually disappear if it is kept scrupulously clean and the patient is kept at rest in bed. Repeated lumbar puncture is useful in some cases as a means of hastening the shrinkage of a fungus cerebri.

FOREIGN BODIES

Ample material is now available for forming a judgement, not final, perhaps, but at any rate sufficiently definite to guide the treatment of cases where a projectile remains lodged in the brain.

The idea that all foreign bodies should be removed, either primarily or secondarily, and whether causing symptoms or not, so widely held at the beginning of the war, has happily been abandoned.

The mortality alone, to say nothing of the possible cerebral damage in the cases which 'recovered', was, at least earlier in the war, very high. Thus two series of cases are quoted in the *Revue Neurologique* (June 1916) of operations for the removal of bullets or shell-splinters, where of 93 patients no fewer than 60 per cent. died. Amongst the early cases operated on by one of us there were 12 deaths in 28, a mortality of 43 per cent. Naturally all these fatalities were not directly due to the removal of the foreign body, but some undoubtedly were. One has to distinguish between missiles which are situated very deeply and those which remain close to the entrance wound. In the latter case removal of the missile naturally forms part of the primary toilet operation.

It is well known that foreign bodies are perfectly well tolerated in the brain. Makins, in his *Surgical Experiences in South Africa*, says: 'The experience of civil practice has already sufficiently proved the small amount of inconvenience likely to follow the retention of a bullet in the skull.' If the operation could leave behind a perfectly normal brain, doubtless the patients would be better off after removal. Pierre Marie, speaking of 80 cases under observation in which the missile was perfectly tolerated, says: 'The lesion has been produced, and the removal of the foreign body can have no influence upon it; on the contrary, the operation necessitates a new trephining, a new opening of the dura mater, and the division of new projection or association fibres. Slight lesions may be aggravated, and the functional disability made worse.' Gordon Holmes traced 164 cases with projectiles remaining in the brain, all of over three months' duration, and 95 of between two and three years' duration. Twenty-three of these patients were on active service, and of the 129 discharged from the army 36 were in civil employment and 12 had died. Of the fatal cases two died after removal of the missile at a secondary operation, three from cerebral abscess, and one from meningitis. There were three other cases of abscess in this series, all of which recovered. Nine of the 164 patients suffered from fits.

It would be as wrong to state that no deep missile should ever be deliberately removed as to say that all should be. What symptoms exactly can be traceable to their presence it is difficult to say, for every

symptom and combination of symptoms found in the carriers of projectiles are also found in patients with cranio-cerebral wounds without retained missile. Abscess occurs in patients with retained missiles, it is true, but the percentage is not very much higher than after all classes of head injury, including those with intact dura mater. Nor does the abscess necessarily form round the foreign body ; on the contrary, it is more apt to occur in some portion of the track nearer to the point of entrance. Of this fact we have seen several instances. It would seem that the track becomes progressively cleaner from the wound to the foreign body. The removal of the foreign body does not rid the patient of the chance of abscess formation, though possibly it may diminish it. But the operations for the removal of missiles are not free from danger either to life or to cerebral function.

The balance of evidence, therefore, is in favour of non-interference.

Perhaps a special note may be made of shrapnel balls and rifle bullets. There we are dealing with comparatively heavy masses of metal, the weight of which may possibly produce softening of the surrounding brain and give rise to symptoms of late development, apart from abscess formation. Shrapnel balls and whole rifle bullets have occasionally been noted to change their position in the brain. These, then, may fall into a different category, and their removal *à froid* may comparatively often be justifiable.

EPILEPSY RESULTING FROM CEREBRAL INJURIES

Amongst 6,664 cases collected by Tuffier and Guillain in the neurological centres of the French army, there were 676 cases of epilepsy, or about 10 per cent. This includes all cases which were known to have had fits at any period, even in the earliest. Now as it is well known that in the first few days after the injury occasional fits occur in many who, so far as can be ascertained at the present time, get no recurrence, it is clear that the figure of 10 per cent. is probably an over-estimate.

Adie and Wagstaffe, in reporting 656 early cases, stated that fits occurred in 5 per cent. and that the time of onset was always within the first seven days after operation, or (if already operated upon) after transfer from the clearing station to the neurological centre farther down the line. Further, the fits were never spread out over a period longer than three days, and they never recurred.

Pierre Marie (*Revue Neurologique*, June 1916) examined 1,131 cases from the point of view of epilepsy. He found that 59 patients had had fits (5·2 per cent.), which in 28 instances were Jacksonian, and in 31 were general. The longest interval between the date of the wound and the onset of the fits was 18 months.

In yet another series of 247 cases observed by Henri Claude, epilepsy,

either Jacksonian or general, occurred in 10 per cent. All these cases had been trephined.

In 610 cases traced after evacuation to England of whom they had complete notes, Sargent and Holmes found that 37 (6 per cent.) had had fits. In 8 of these only one convulsion had occurred.

The class of cranio-cerebral wound associated with epilepsy is important. With regard to early fits, Adie and Wagstaffe say that a definite relationship exists between the nature of the wound and the occurrence of the fits, for they were commonest in cases of scalp wound in which at the operation no injury to the skull was apparent, or in which an intact or very slightly damaged dura was found under a depression.

In Sargent and Holmes's series, 33 of the 37 cases in which fits had occurred had had severe compound fractures of the skull with laceration of the dura mater and direct injury of the brain ; one of the remaining four patients had been an epileptic since 8 years of age.

Jalagnier (*Revue Neurologique*, June 1916) states that epilepsy is more frequent in those in whom there has been loss of cerebral substance, and that the attacks commence usually 2–3 months after healing. He attributes them to adhesions between the scalp and the dura mater.

There appears to be a difference, a view which is supported by the figures and opinions quoted, between the type of wound associated with the early evanescent fits, and those found in patients with later and more persistent fits. Our own experience points in the same direction ; most of the patients with fits of later development are those with cranial defects through which the scalp adheres to the membranes and brain. The fact of adhesion of the scalp to an intact dura does not seem to be of the same importance as the adherence of the brain to the dura mater, especially in cases where there has been much loss of cerebral substance. So far as it goes this observation would seem to indicate that the practice of opening an intact dura to ' let out pulped brain ' would at least not tend to diminish the chances of future epilepsy.

The actual cause of traumatic epilepsy is obscure. All the gross lesions found in post-traumatic epilepsy also occur in the very large numbers of patients who never have fits. These gross lesions therefore cannot alone be the cause, though they may serve as the spark to fire the powder in patients who are in some obscure manner predisposed to be epileptic.

Fits are of two kinds, general and focal or Jacksonian. The general fits bear no relationship to the site of injury, whereas the focal attacks begin with symptoms, motor or sensory as the case may be, referable to the injured part of the brain. If they originate in a cerebral area not directly beneath the cranial wound, they are evidence of other injury,

whether by contre-coup or the deep penetration of a missile. Jacksonian fits are not limited to lesions of the motor area. They may begin with subjective visual phenomena, 'sensations' in the face, limbs, or elsewhere, or affections of speech or hearing, and thence proceed to muscular movements and may finally become generalized. Others may not go beyond the sensory stage.

In the early and evanescent fits the gross lesions are local concussion and contusion; minute hæmorrhages into the brain or beneath the pia; and small subarachnoid hæmorrhages. In the fits of later onset a distinction must be made between those associated with active or recrudescent sepsis, and those in which no evidence of such sepsis is forthcoming. In the former case the fits may be evidence of abscess formation or of the onset of encephalitis or meningitis, which may or may not be associated with the presence of bony spicules or of retained missiles. There is no evidence that foreign bodies, whether bony or metallic, play any but an occasional and accidental part in the production of epilepsy, nor, indeed, are they often found in the subjects of traumatic epilepsy. In Holmes's latest series there were only 9 patients with epilepsy amongst 164 'carriers' of metallic foreign bodies, giving a rate of 5·5 per cent., which is lower than the general rate for all classes of head injury given by Tuffier and Guillain, and almost exactly the same as the figure arrived at by Pierre Marie in a study of 1,131 cases. Apart from sepsis, dense scars, cysts, localized gliosis, and, above all, adhesions between brain and scalp, are found.

Treatment.—Surgical. The experience of war wounds unhappily bears out that of civil practice, that surgery can do little for traumatic epilepsy. An operation will often modify the character of the fits, and even abolish them for a variable period. It is possible that if a satisfactory means can be found for separating an adherent brain from the scalp, and preventing the recurrence of the adhesion, some cases may be favourably affected. The means hitherto tried have not had a great measure of success. Cargile membrane, or other absorbable tissue interposed between the brain and its coverings only results in the formation of still more dense scar tissue. The mere closure of the cranial defect by plastic or grafting methods is unlikely to effect a cure, and indeed the occurrence of fits is regarded by some as a contra-indication for cranioplasty.

When, on the other hand, there are indications that a recrudescence of sepsis is at the bottom of the attacks, then the removal of infected fragments, or the drainage of an abscess, are indicated.

Medical. Even in the most favourable circumstances no surgical procedure can alone be expected to effect a cure. After any operation the same treatment must be adopted as for the far more numerous

class for which no surgical interference is advisable. This consists, briefly, in a prolonged period of complete physical and mental rest the regular administration of bromides, the absolute avoidance of alcohol, and the general regulation of the patient's life and habits.

INSANITY

Little need be said on this point, except that it is quite certain that serious mental symptoms are very rare as a result of gunshot wounds of the head. At an early stage slight evidences of mental disorder are fairly common, and they are mostly observed when the frontal region is the site of the injury. At a later stage Holmes found only 10 cases of insanity amongst 2,357 patients. Of these 2 were instances of transitory mania, and one a case of delusional insanity probably independent of the cranial injury. The rest of the patients were melancholic, irritable, or irresponsible, and 4 recovered quickly. These were mostly men with serious injuries of the frontal lobes.

Professor Mott (quoted by Sargent and Holmes) writes: 'Personally I am very sceptical of a large number of cases of insanity arising from traumatic causes. I went into this subject very fully some years ago, and came to the definite conclusion that head injury, apart from syphilis, alcohol, and hereditary neuropathic taint, was seldom the cause of mental affection.'

CRANIAL DEFECTS

Traumatic and operative defects in the cranium are, of course, frequently met with and are often associated with symptoms with which they have no obvious causal connexion.

Many patients ascribe, however, some or all of their discomforts and disabilities to the cranial gap; some live in constant fear of receiving an injury upon the unprotected brain; some object to the sensation of bulging when they stoop or strain; others regard the opening as an abnormality which 'gets on their nerves', while tenderness around it is sometimes a source of great distress. In a few, who present no symptoms, the actual deformity, particularly in the frontal region, is a source of annoyance, or is a handicap in obtaining employment. Cranioplasty, therefore, has its place as an æsthetic or a protective procedure, but as a therapeutic measure it is still upon its trial. Pierre Marie observed 21 cases of cranioplasty: 6 received 'some benefit'; 3 were made worse; and 12 were unaffected. According to the taste of the operator, the defect may be closed by cartilaginous grafts taken from the ribs; by bony grafts from the tibia; by a bony plate cut from the outer table of the skull close to the gap; or by

plates fashioned from gold, silver, zinc, aluminium, or celluloid, perforated or unperforated, and fixed to the skull beneath the scalp by any of a large number of different devices.

MILITARY VALUE OF TREPHINED PATIENTS

Tuffier quotes 4,943 cases dealt with by the Pensions authorities, and classified as follows: 1,287 discharged; 1,559 temporarily discharged; 1,802 returned to the auxiliary services; 295 returned to armed service. That is to say that 44 per cent. were preserved to the Army in one form or another.

SUBJECTIVE SYMPTOMS

The incidence of subjective symptoms, and the degree of incapacity caused by them, are difficult to estimate. They can scarcely be presented statistically.

Pierre Marie stated that out of 323 patients who had been trephined, 98 had subjective troubles independent of the site of the lesion, i.e. slightly more than 30 per cent.

Holmes and Sargent, as a result of the investigation of 1,239 old cases of gunshot wound of the head in 1916, wrote as follows:

'Various subjective symptoms, which cannot be attributed to any local injury, are also remarkably frequent and necessitate the invaliding of many men from the Army. The most common of these is pressure or throbbing in the head, which is increased by noise, fatigue, exertion, or emotion; attacks of dizziness, and nervousness or deficient control over the emotions and feelings. Many too exhibit a considerable change in temperament; they are depressed, moody, irritable or emotional, and unable to concentrate attention on any physical or intellectual work. A few have had major hysterical symptoms such as paralysis, anæsthesia or visual disturbances.

'These symptoms are very similar to those seen in neurasthenia, and especially when this condition has been of traumatic origin. They certainly incapacitate the subjects from active service, but they are, on the other hand, recoverable. They are entirely independent of the site or severity of the original wound, and are often as severe when the scalp only has been injured as in serious compound fractures of the skull. They seem to develop equally whether an operation has been performed or not.'

HEADACHE

One of the commonest and most disabling sequelae of head injuries is persistent headache.

As one of a group of neurasthenic symptoms, it is not infrequently

a prominent feature, but it often occurs as an apparently solitary symptom in men otherwise in good general health and free from signs of gross cerebral lesion. Its pathology is obscure. Two explanations are forthcoming, one mechanical and the other functional.

The mechanical view supposes a state of increased intracranial pressure, varying from time to time and under different conditions of occupation or activity entailing considerable variations of blood pressure. One of the most constant features in the gross pathology of gunshot injuries of the brain is distension of the ventricles. It is found in almost every brain, whatever the degree of injury, which has been hardened in formalin before being cut. It is the accumulation under pressure of fluid which causes the ventricular lining to herniate into the softened brain in septic cases, and ultimately to gain relief by rupture. It seems probable that this excess of cerebro-spinal fluid in cases of head injury is due to hyper-secretion by the choroid plexuses, because, as Halliburton and Dixon have shown, the strongest stimulus to this secretion is an emulsion of brain, and the products of such emulsion must always be absorbed whenever the brain tissue is lacerated.

In cases of cerebro-spinal fistula resulting from penetrating wounds, the degree of headache varies in a very striking manner with the amount which leaks through the fistulous opening.

Again, in our experience patients with closed skulls, or with intact dura mater, are more subject to headache than those with large cranial defects. Patients with large bony openings and concave pulsating scars rarely suffer from severe headache. The presence of a retained missile, except in so far as a mild degree of encephalitis may surround it or the track leading to it, does not appear to have any causal relation to headache. We have seen cases where the patient himself has attributed his pain to the presence of a missile, but many more where the carrier of such a projectile is entirely free from headache. The fact that the dura mater is an inelastic membrane sensitive to pinching or stretching; the common personal experience that straining and stooping aggravate an ordinary headache; and the intense pain suffered by persons with cerebral tumour or meningitis, all support the view that post-traumatic headache may be due to increased intra-cranial pressure. Further, decompressive operations have sometimes been followed by relief,[1] whilst rest in bed, lumbar puncture, and purgation in some cases give at least temporary relief.

But all post-traumatic headaches cannot be explained in this way.

We have seen cases in which lumbar puncture reveals no obvious increase of cerebro-spinal pressure, and the withdrawal of fluid by this means gives no relief. The onset of headaches, again, may occur only

[1] See L. Bathe Rawling, *B.M.J.* 19/4/19, p. 476.

after a long interval from the date of wounding or from the date of cessation of earlier headaches. Decompressive operations are not always followed by cure.

We must therefore, for the present, express the view that whilst many headaches may be due to increase of intracranial pressure, yet there are other factors underlying their causation.

The frequency and severity of headache, and the influence of treatment, are difficult to estimate. We have attempted to do so in a considerable number of cases in the following manner: three of the upper lines of the temperature chart are devoted to recording whether the headache is absent, slight, or severe. The sister who makes the observations does so six times a day at stated hours, and she records, not what the patient tells her, but what she considers to be the state of affairs from his manner and behaviour. As the same sister makes the observations, we get an approximately correct record. In order to depict so large a number of observations graphically, we plotted out the number of headaches per week. A record of 462 observations extending over eleven weeks, shows the effect of absolute rest in bed upon the ' headache chart '.

Treatment. Many patients are found to have had no definite period of rest in bed. Some, perhaps for long periods in hospital or convalescent home, have been allowed to get up and participate in the ordinary activities of the ward when so inclined, and to remain in bed for a day or two when suffering from headache. Others have been returned to civil or military employment too soon, and have developed chronic or intermittent headache in consequence.

Whilst in a refractory case a decompressive operation might occasionally be advisable, it should, in our opinion, never be lightly undertaken, nor until after a long period of absolute rest in bed together with the regular administration of bromides; and the transition from this rest to the ordinary activities of life should be very gradual.

INJURIES OF THE SPINE

BY

COLONEL E. FARQUHAR BUZZARD

AND

LIEUT.-COLONEL PERCY SARGENT, D.S.O., C.M.G.

INJURIES OF THE SPINE

SPINO-VERTEBRAL TOPOGRAPHY

THE spinal cord is remarkably well protected from the effects of violence. It is suspended in fluid within a tough fibrous sheath, which in its turn is supported by a packing of fatty cellular tissue, rich in veins, separating it from the strong bony envelope of the spine. The spinal nerves leave the canal through bony foramina which, according to the level concerned, may be close to or at a considerable distance from the spinal segments with which they are connected. In all cases, however, the spinal ganglia lie just within their own corresponding intervertebral foramina. The cord itself ends at the lower level of the first lumbar spinous process. The lower part of the canal is occupied by the lumbar and sacral nerves. Hence injuries of the lumbo-sacral spine involve the cauda equina and not the spinal cord. The cervical enlargement, corresponding to the segments supplying the upper limbs (C. 5, 6, 7, 8, and D. 1 and 2) ends opposite the 7th cervical spinous process. The lumbar enlargement, corresponding to those segments which supply the lower limbs, lies opposite the last three thoracic spinous processes. The spinal theca ends at the second sacral spine. In consequence of the fact that the cord is shorter than the canal which contains it, the various segments do not lie opposite the corresponding vertebræ, but at a level which becomes relatively higher and higher from above downwards. The Table indicates the relative level of the segments and spinous processes.

TABLE

(From Cunningham's *Anatomy*)

Spinous Process.	*Segment.*
C. 1	C. 2
2	3 and 4
3	5
4	6
5	7
6	8
7	Th. 1 and 2
Th. 1	3
2	4
3	5 and 6
4	7
5	8
6	9
7	10
8	11
9	12 and L. 1
10	L. 2
11	3 and 4
12	S. 1, 2, 3
L. 1	4 and 5

PATHOLOGY

In gunshot wounds of the spine there is no constant relationship between the damage to the vertebræ and the severity of the cord lesion, which depends chiefly upon the velocity of the projectile which causes it. A shrapnel ball, for instance, may break up two or three neural arches and be found lying partly within the vertebral canal, and yet the cord injury may be far from hopeless. On the other hand, a tiny fragment of shell may enter the canal and sever the cord with scarcely any damage to the bones, whilst a high velocity rifle bullet may merely touch a transverse process in passing, and yet produce softening of the cord with more or less complete loss of function at that level.

Nature of the Cord Lesions. In his Goulstonian Lectures (1915), Gordon Holmes has described in detail the effects upon the cord of the following three types of gunshot injury:

1. Direct injuries.
2. Contusion and compression.
3. Concussion.

The three classes, of course, overlap. Both the gross and microscopic changes are similar in nature, and the differences which exist are almost wholly differences of degree.

Starting from the point of maximum intensity of the damage, these changes extend both upwards and downwards in the cord for a distance of several (3 to 5) segments. They consist of punctiform hæmorrhages, areas of necrosis, and in many cases a peculiar cavitation, which has been fully described by Holmes. The hæmorrhages are rarely other than minute, and no case was encountered to which the term hæmotomyelia could properly be applied.

The nerve fibres suffer in varying degree from total disruption to a mere swelling with separation of neuro-fibrils and fragmentation of the myelin sheath; in the same tract or area some fibres escape altogether, whilst others are quite destroyed. Amongst the nerve cells, necrosis and chromatolysis are commonly observed.

The most striking features of the lesions found extending in both directions from the site of maximum injury are *œdema* and *cavitation*. The former diminishes centrifugally; it leads to degeneration of neuroglia as well as of the nervous elements. The peculiar cavitation described by Holmes affects not only the grey matter but the white strands, and is almost wholly confined to the dorsal columns. The fluid in these spaces is under pressure, and displaces rather than destroys the nerve fibres.

The bearing of these observations upon the question of surgical

interference is obvious. It neither encourages operation nor is it flattering to the surgeon who regards with honesty the few cases where any considerable improvement has followed his operation. For it is clear that except in those instances where continued pressure exists, operation can have no direct bearing upon recovery. Not only is the number of cases with continued pressure relatively very small, but even amongst those the cases where such pressure is being exerted upon recoverable cord are extremely few. If we look at the records of 70 cases (Holmes and Sargent) in which the cord and vertebral canal were examined from this point of view, 36 at operation and 34 in the post-mortem room, we find that evidence of some degree of pressure could be obtained in 30, and none in 40. It is perhaps as well to note that the proportion in which pressure was noted at operation is very much higher than that found post-mortem, namely 55 per cent. to 28 per cent. The opportunity for more thorough examination in the post-mortem room makes it probable that figures from this source are the more accurate. It was rare, however, to find any definite narrowing of the canal, and still more rare to find such a degree of narrowing as the cord can tolerate without evincing symptoms of compression in cases of spinal caries. It has been suggested that a relatively slight degree of pressure may so influence the vascularity of the cord as to produce a continuance or an increase of the symptoms. This may be so, but direct evidence is lacking. Indeed, the buffer of cerebro-spinal fluid is so considerable that the spinal canal would have to be very appreciably narrowed before any pressure could be brought to bear upon the blood-vessels of the cord, and, if the pressure were exerted by metallic bodies or bony fragments through the ruptured dura, there would be so much direct destruction that the amount of recovery to be expected from relief of pressure, would be insignificant.

Injury of Meninges. In 44 cases out of 81, in which direct evidence was forthcoming, the theca was found to have been opened, either by the missile or by an indriven fragment of bone.

The most usual lesion is a linear vertical tear in the dura of from one half-inch to an inch in length, a type suitable for closure by a simple continuous suture. Occasionally there is an irregular gap resulting from actual loss of substance, and in yet another class of case the dural lesion is represented by a mere puncture produced by a spicule of bone.

It is rare to find cerebro-spinal fluid escaping from the wound, but this has been noted in a few cases. Even when the dura has been found torn, cerebro-spinal fluid may not be seen to escape at operation until the theca has been fully exposed by removal of torn muscle, bloodclot, or bony fragments. Now and then the spicule of bone which has caused the tear acts as a cork, and prevents leakage. In other instances the

membranes and lacerated cord have been found sealed together in such a way as to prevent the escape of fluid. The importance of the integrity of the theca in relation to meningitis is obvious, and the possibility of an avenue of infection being opened up has to be taken into account when the question of operation is being considered. It should be remembered that a comparatively slight meningeal injury may give rise subsequently to signs of a compression paraplegia owing to the formation of a loculated cystic condition at the site of trauma.

Types of Fracture. It is unnecessary to describe in any detail the various types met with. The only question of practical importance in this connexion is that of indriving of fragments of bone into the vertebral canal. Depressed fractures of the kind met with in the skull have not been frequent in our experience, but their possible presence should be remembered. We may cite an extreme case of this kind in which the fuse cap of an anti-aircraft shell, falling from a great height, struck a patient fairly and squarely upon the mid-dorsal vertebræ. Here the damage was very great, and whole or almost whole laminæ were indriven so as actually to compress the cord. On the other hand, we have seen the impaction of a piece of shrapnel on the lateral aspect of a laminal arch produce a depressed fracture of the latter by means of a splinter detached from its internal surface, the removal of which by operation had very happy results.

One of the commonest conditions in which bony fragments are found within the spinal canal is that in which a shrapnel ball—sometimes the base of a rifle bullet or fragment of shell—lies partly within the canal with fragments of a lamina between it and the theca.

Small pieces of bone are sometimes found within the spinal canal, having been driven in by a missile which passes across close to the vertebral column just touching some bony projection *en route*. When a bullet has traversed the canal, small fragments may be expected to be found embedded in the disintegrated cord.

Indriven spicules sometimes puncture the dura, and their withdrawal causes an escape of cerebro-spinal fluid.

DIAGNOSIS

The symptoms depend upon the site and severity of the cord injury. How far the medullary lesion is destructive, and therefore irrecoverable, and how far the loss of function is due to concussion or to other recoverable causes, can rarely be ascertained in the earlier stages. Nor at first can any reliable opinion be arrived at as to the prognosis. In other words, the degree of completeness of a transverse lesion of the cord cannot be ascertained in the stage of spinal shock.

At first the motor paralysis and sensory loss are almost always complete, and all reflex activities are abolished below the level of the lesion. Gordon Holmes writes : ' The state of tone in the muscles of the lower limbs, and the reflex movements that can be obtained from the soles, are the only reliable indications. Within the first two weeks stimulation of the soles generally gives no reflex response in the severest cases ; in less severe cases there may be isolated flexion of the great toes, or this movement associated with contraction of the hamstrings, while in more favourable cases a withdrawal reflex of the limb with extension of the great toes, and often dorsiflexion of the foot (Babinski's sign) is obtained. Account must be taken of the level of the injury, as lesions of the lumbo-sacral cord and cauda equina more readily abolish these reflex movements, and the tone of the muscles, than more highly placed injuries.' Repeated examinations are necessary before a correct diagnosis can be arrived at.

After the shock effects have passed off the severity of the lesion can best be estimated by the return or absence of return of motor and sensory function. The recovery of reflex automatic functions in that part of the cord which lies below the level of the lesion may be expected whether or not the latter amounts to a complete anatomical division. The speed with which the reflex activity returns in complete transverse lesions depends upon the general condition of the patient and upon the presence or absence of septic complications. In favourable cases, in which the lesion is above the lumbo-sacral enlargement, the knee and ankle jerks may reappear two or three weeks after the date of injury. When cystitis, bed-sores or septic wounds are present the reflex recovery is delayed until these complications begin to clear up, and the jerks may again be lost in the presence of any septic relapse, such as an attack of pyelo-nephritis with pyrexia and other constitutional disturbances, or the development of a fresh bed-sore. With the recovery of tendon jerks the general tone of the musculature in the lower limbs improves, spasticity replaces flaccidity, and the patient's comfort may be disturbed by the development of involuntary flexor spasms, which must not be mistaken for voluntary movements nor for an indication that the prognosis is in any way more favourable.

What has been said in regard to the reflex actions of the lower limbs applies equally to those of the bladder and rectum. These organs may develop the power of automatic evacuation at periodic intervals, even when the lesion of the spinal cord precludes any possibility of recovery in regard to voluntary action. This again is favoured by the absence of cystitis, pyelo-nephritis, bed-sores, and other septic complications, and is in itself of great advantage to the patient and to his nurses, in that it

makes cleanliness more easy to attain and does away with the necessity for catheterization.

We cannot here enter into a consideration of the extremely interesting and important work of Head and Riddoch regarding the signs by which totality of a lesion may be recognized. We are concerned with the question whether any useful degree of recovery is to be expected, and what assistance can be given towards alleviating the lot of the paralysed or partly paralysed man.

Examination of a Case of Spinal Injury. This must be both systematic and accurate. So long as both these points are observed a comparatively simple neurological examination suffices, such as can be carried out by those who may not have had sufficient neurological training or experience to allow of their using and interpreting the more complicated methods of neurological investigation. The motor, sensory, and reflex functions should in turn be examined and recorded at the time that the observations are made.

(*a*) *Motor.*—The nutrition, tone, and position of the paralysed limbs should be observed and recorded. The expression, 'the legs are partly paralysed,' means little or nothing ; a note as to what movements the patient can make voluntarily at the hip, knee, and ankle joints, gives definite information, which is of value. In some cases an investigation of the electrical reactions of paralysed muscles may be helpful.

(*b*) *Sensory.*—Examination with a sharp pin reveals the extent of any loss of sensibility to pain ; a wisp of cotton-wool on hairless parts indicates any loss to light touch ; pinching the muscles elicits the presence or absence of deep pain sensibility. Sensibility to temperature can readily be tested by hot and cold test-tubes. Impulses of deep and superficial pain, and of heat and cold, are conveyed by fibres which cross the cord and pass up in the lateral columns of the opposite side. Impulses aroused by light touch cross the cord more leisurely and travel upwards in the lateral columns of the opposite side. Impulses subserving the sense of position and movement, of discrimination, of localization, and of vibration pass up in the posterior columns of the same side of the cord. When superficial pain is lost and deep pain is preserved in an area it is an indication that the lesion affects a spinal root rather than a spinal segment.

(*c*) *Reflexes.*—The absence, or degree of activity, of the arm jerks, knee jerks, and ankle jerks of the two sides should be recorded, and the abdominal reflexes should be carefully tested. Particular attention should be paid to the nature of the reflex obtained by stroking the sole of the foot. The presence of involuntary reflex spasms and their nature should also be noted.

(*d*) *Sphincters.*—The state of the vesical functions is of great importance, and the nature of any interference with these functions should be noted—whether there is retention and distension with overflow, periodic involuntary evacuation, or merely lack of control in the direction of difficulty in commencing the voluntary act (hesitancy), of inability to arrest the act when the desire for evacuation arises (precipitancy), and so on.

(*e*) *Sympathetic system.*—The occurrence of sweating in particular areas is sometimes a matter of importance. Paralysis of the oculo-pupillary fibres gives rise to the characteristic signs when the lesion is above the level of the 2nd dorsal segment.

A systematic examination on these lines will give a very fair indication of the degree of conductivity remaining in the cord. A series of such examinations repeated at intervals of a few days, or two or three weeks, will give information as to the progress of any recovery which may be taking place.

The *level* of the cord lesion can only be ascertained by a neurological examination, but additional information may be gleaned from a consideration of the position of the wound or wounds, the probable direction of the missile, as well as from a good radiographic investigation of the bony structures.

The cutaneous distribution of the spinal segments is indicated in Fig. 133, and the segmental supply of the muscles in the upper and lower limbs is given in Tables I and II.

TABLE I

SHOWING THE MUSCULAR DISTRIBUTION OF THE VARIOUS NERVE ROOTS OF THE BRACHIAL PLEXUS [1]

C. 5. *Deltoid. Spinati. Teres minor. Rhomboids.* Diaphragm. Biceps. Supinator longus. Serratus magnus. Pectoralis major. Brachialis anticus. Coraco-brachialis.

C. 6. *Biceps. Coraco-brachialis. Brachialis Anticus. Supinator longus.* Deltoid. Spinati. Teres major. Serratus magnus. Pectoralis major. Subscapularis. Pronators of forearm. Extensors of wrist.

C. 7. *Triceps. Extensors of wrist and fingers.* Pronators of forearm. Pectoralis major. Subscapularis. Latissimus dorsi. Teres major.

C. 8. *Flexors of wrist and long flexors of fingers.* Interossei and lumbricales. Muscles of thenar and hypothenar eminences.

D. 1. *Muscles of the thenar and hypothenar eminences. Interossei and lumbricales.* Flexor carpi ulnaris. Oculo-pupillary fibres.

TABLE II

SHOWING THE MUSCLES INNERVATED BY THE DIFFERENT ROOTS OF THE LUMBAR AND SACRAL PLEXUSES [2]

L. 1, 2. *Iliopsoas. Quadratus lumborum.* Sartorius. Cremaster. Quadriceps.

L. 3. *Quadriceps.* Sartorius. Quadratus lumborum. Adductores femoris. Obturator externus.

L. 4. *Adductores femoris.* Quadriceps. Sartorius. Tensor fasciæ femoris. Tibialis anticus. Extensor communis digitorum. Extensor hallucis.

L. 5. *Tibialis anticus. Extensor communis digitorum. Extensor hallucis.* Peronei. Abductors and external rotators of the hip. Gastrocnemii. Long flexors of the toes. Hamstrings. Glutei.

S. 1. *Gastrocnemii. Hamstrings. Long flexors of the toes.* Peronei. Abductors and external rotators of the hip. Glutei.

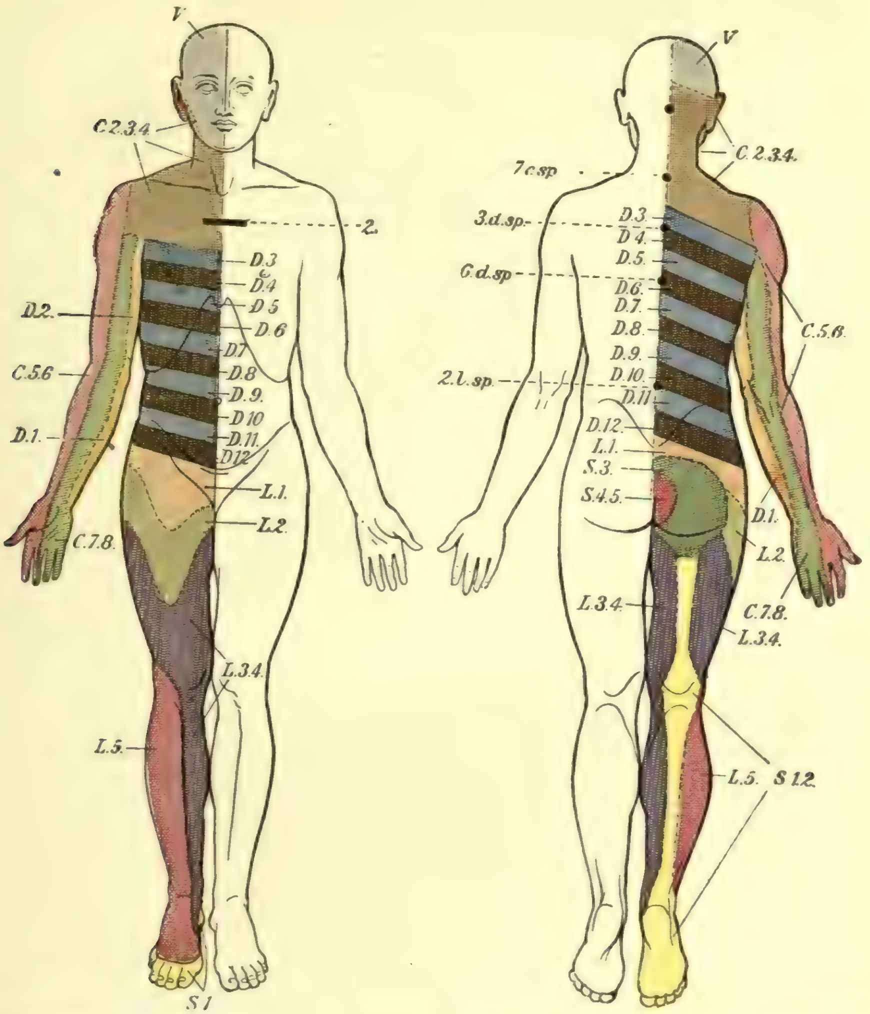
S. 2. *Glutei. Intrinsic muscles of the foot.* Gastrocnemii. Hamstrings. Long flexors of the toes.

S. 3, 5. *The musculature of the perineum connected with defæcation, micturition.*

[1] Those muscles which are most useful ' landmarks ' for individual segments are printed in italics.

[2] The muscles which afford the most useful landmarks are printed in italics.

DIAGRAM SHOWING THE RADICULAR SENSORY AREAS OF THE HUMAN BODY



Copyright. FIG. 133. *By Dr. E. Farquhar Buzzard.*

This diagram has been compiled by the writer from a study of similar diagrams published by others, and modified in accordance with his own experience.

Although the various areas depicted in the diagram are essentially Root Areas, the information they supply can be used clinically for the purpose of localizing both radicular and intramedullary lesions. It must be remembered, however, that the deductions in the one case are different from those in the other. If, for instance, the character of the sensory change in one of these areas is of the peripheral type, a radicular lesion of the corresponding segmental level may be diagnosed ; if, on the other hand, the sensory loss is of the central type in a particular skin area, the spinal lesion must be sought at a level several segments higher than that which corresponds to the sensory area.

For practical purposes it is important to remember that the uppermost level of sensory change (not the upper level of total analgesia) should be compared with the nearest corresponding line on this diagram.

If employed with an intelligent appreciation of these points, the diagram is of much clinical importance, but it should not be exploited blindly as a mechanical calculator. Individual variations alone are sufficient to demand a considerable margin of error.

DIAGNOSIS OF ORGANIC FROM FUNCTIONAL PARAPLEGIA

Men who have received wounds in the neighbourhood of the spine, or who have been knocked over or buried, sometimes present symptoms which may be confused with those of paralysis of organic origin. These cases of hysterical paraplegia present very variable pictures, but may be roughly divided into two categories : (1) patients who lie bedridden, generally completely paralysed and anæsthetic from the waist downwards, and (2) patients with some kind of difficulty in walking which may give rise to any kind of extraordinary gait.

The diagnosis of the bedridden patient is generally easy for the following reasons : (*a*) The abdominal and plantar reflexes are normal, and the tendon jerks are neither absent as in organic flaccid paralysis, nor associated with clonus and involuntary flexor spasms as in the spastic paraplegia of organic origin. (*b*) There is no disturbance of sphincter control, although in some instances the patient has been provided with a urinal constantly in position, and there is no tendency to cystitis. (*c*) Bedsores do not develop. (*d*) If the paralysis is incomplete it does not affect certain movements more than others, as is the rule with organic cases. (*e*) Attempts at voluntary movement are generally associated with an irregular clonic tremor of the limb in action, which is quite unlike any organic tremor. (*f*) When the paralysis involves the trunk and lower limbs from the waist downwards attempts to sit up in bed are not accompanied by the drawing upward of the umbilicus, nor by the elevation of the legs from the bed, as is observed in patients suffering from organic spastic paraplegia. (*g*) The upper level of sensory loss is very variable and very open to suggestion by the observer. (*h*) Although there may be some general wasting from disuse, the nutrition of the skin, hair, nails, and muscles is well maintained, and there is a remarkable absence of the œdema, sweating, and desquamation so often seen in organic cases. (*i*) The muscles present normal electrical reactions even after they have been out of use for many months or even years.

The diagnosis of the hysterical gait may not be so easy unless the observer has considerable experience in regard to the gaits produced by organic disease. It must depend on the systematic examination of the motor, sensory, and reflex functions of the affected limb or limbs with the object of excluding any possibility of an organic basis for the disorder. In many of these cases the patient complains of some pain in the back or leg during the attempt to walk, and great care must be taken not to overlook any possible source for its organic origin.

Visceral Complications. Few cases of spinal injury in which the abdominal viscera were also wounded reached the base hospitals in France, and scarcely any lived to arrive in England.

A comparatively large number of patients with coincident injury of the lung reached the home hospitals, and the possibility of this complication should always be borne in mind.

Cystitis, however, is extremely common—indeed it almost constantly occurs in the cases with urinary retention, and is by far the most common cause of death.

The problem of preventing cystitis has received much attention, but no solution is as yet forthcoming. It has long been supposed that the cystitis in these cases results from catheterization, and that consequently it can be prevented if the use of the catheter is avoided. This belief, however, is untenable in view of certain facts : Firstly, the organisms found in cystitis are almost without exception of intestinal origin. It is hardly probable that a catheter would always carry in these organisms to the exclusion of the common microbes likely to be found upon a dirty instrument, or an unwashed glans penis. Secondly, cystitis occurs almost, if not quite, as constantly when no catheter has ever been passed. Some of the worst cases of cystitis have been seen in men who had been 'lying out' for days, and who during that period had suffered from retention of urine unrelieved by catheterization.

The fundamental factor is the functional disturbance of the bladder. Cystitis does not occur in cases of spinal injury where no such disturbance exists. Where a temporary impairment of function has been present, lasting for two or three days only, it may not occur, or, if it does, is of a mild and transient type. In those cases where the bladder function is regained after an interval of a few weeks or longer, the cystitis diminishes and gradually clears up *pari passu* with the functional recovery.

Further, Head and Riddoch have shown that, even in cases of total and irrecoverable cord lesion, when a vesical reflex can be established by the means which they have described ('the automatic bladder'), cystitis will clear up, or at least will be held in check.

The ideal method of preventing cystitis should include the avoidance not only of sepsis but of vesical distension, so that during the interval between the infliction of the spinal injury and the return to normal control, or the development of an automatic bladder, there may be less risk of secondary renal infection and the establishment of pyelo-nephritis. Whatever may be the exact path of ascending renal infection it seems probable that vesical distension plays a part.

The bladder may be emptied at intervals either by the use of a catheter or by manipulation. Both methods are open to the same objection in practice, i. e. they do not prevent over-distension owing to the fact that urine is not secreted at the same rate throughout the twenty-four hours. Manual 'expression' is not an easy procedure, and is not altogether devoid of risk from rupture of the bladder. A catheter tied into the

bladder affords continuous drainage, and thus prevents distension and minimizes the risk of infection from without. This method can be practised for a limited period of time without damage to the urethra, and if automatic evacuation is developed within that period, it is probably the safest procedure to adopt.

An early supra-pubic drainage has some theoretical advantages, but in practice has not been a great success owing to the difficulty in preventing leakage, especially during transport, and the consequent increase of liability to bed-sores.

In all cases every effort should be made to keep the urine acid and sweet by the internal administration of acid sodium phosphate and urotropin from the earliest possible moment.

Treatment of Cystitis. A paraplegic patient usually lies motionless upon his back. In these circumstances the pus falls to the lowest part and collects around the urethral orifices, whilst the clearer fluid rises to the top. Consequently a catheter, especially a rigid one whose end points upwards, is likely to draw off chiefly the supernatant clearer fluid. In the same way irrigation fluid introduced through a catheter by means of a tube and funnel is likely to pass in and out of the strata lying above the level of the internal meatus, and so to disturb very little the thicker purulent urine lying at a lower level. By the usual method of irrigation by catheter, the urethra is not cleansed ; on the contrary it is likely to be contaminated each time the catheter is withdrawn. If the irrigation is to be done per urethram, it is best accomplished by means of a Higginson's syringe. The nozzle is introduced into the meatus, and the resistance of the sphincter vesicæ is readily overcome by squeezing the bulb : as the fluid rushes in through the internal urethral orifice, the pus upon the base of the bladder is stirred up and so can be removed more easily by the catheter afterwards. By this means, too, the deep urethra is washed out.

It is probable that the good effects of lavage, when thoroughly carried out, are due more to the mechanical flushing than to the antiseptic properties of the fluid used. Solutions of permanganate of potash, quinine sulphate, flavine, and brilliant green all have their advocates.

Supra-pubic Drainage. Opinion is greatly divided upon the indications for and the utility of supra-pubic cystotomy in these cases. Our own views at the present time relate to the operation described below, and not to the usual method of making an incision into the bladder and thereafter draining by means of a loosely fitting tube or a Hamilton-Irving box. After such an operation it is very difficult to keep the patient clean and dry, thereby adding to the danger of bed-sores. This is especially true if the patient with an open bladder has to be moved from hospital to hospital. Further, the bladder which is always kept empty necessarily shrinks, so that if recovery ultimately occurs the organ is so

small that only a very little urine can be retained. The open bladder is little less septic than the closed bladder. Supra-pubic drainage only renders it relatively clean. But the relief of intravesical tension seems to diminish absorption, and probably also shields the kidneys, for a time at least, from ascending infection. We regard the inflamed ulcerated bladder, with its septic contents, as an abscess. The closed bladder, filled as it is in the intervals of catheterization with purulent urine under tension, resembles an unopened abscess from which absorption takes place. From this point of view, therefore, drainage is a good thing.

Whilst the bacterial contents of a septic bladder usually embrace a large variety of organisms, yet in any given case one sort or another may predominate. The most frequent organisms of chronic cystitis are those of the *B. coli* group on the one hand, and those of the *Proteus* group on the other : of the two, infections by coliform bacilli are the more amenable to treatment by lavage per urethram ; the cases in which drainage is most called for are those of proteus infection.

The method which we employ is both simple and efficient. The bladder is filled with fluid by means of a Higginson's syringe, and is then exposed by a short median supra-pubic incision. A puncture is made into it by means of an ordinary Spencer-Wells forceps, and the hole is very slightly enlarged by separating the blades of the forceps. A Guyon's supra-pubic tube is then stretched upon a blunt probe, and pushed in through the puncture. When the probe is removed the tube expands, completely filling the tiny hole. The tube is drawn gently forwards, so that its expanded end rests against the anterior surface of the bladder. No muscle fibres having been divided, and the tube filling the hole, no leakage takes place around it. By means of a glass junction and a long rubber tube, the urine is led off to a vessel hung to the side of the bed. Lavage of the bladder is carried out by means of a Higginson's syringe, the nozzle of which is introduced into the urinary meatus. Should the tube become blocked, it can easily be cleared by syringing. The advantages of this simple operation are :

1. That no leakage occurs around the tube ;
2. That the bladder can be thoroughly irrigated from below, thus preventing the accumulation of pus around the urethral orifices ; at the same time the urethra is kept clean and unirritated by the passage of catheters ;
3. By pinching the exit tube, the bladder can be distended each time the washing is done, so that shrinkage is prevented ;
4. The patient can lie in almost any position, and can sit out in a chair without disturbance of his supra-pubic wound and without the handicap of a mass of wet dressings ; and
5. The little wound will heal rapidly as soon as the need for drainage has passed.

DISABILITIES ARISING FROM SPINAL INJURIES

1. **Pain.** The kinds of pain met with in patients with gunshot wound of the spine may be grouped broadly into four classes :

(*a*) That connected with injury to or pressure upon the posterior roots and ganglia. This pain is of two sorts—spontaneous neuralgic pain, and the pain provoked by stimulation of hyperæsthetic areas.
(*b*) Spontaneous pain, probably of central origin, the actual causation of which is not clear ; it is seen at its worst in cases of concussion of the cervical cord when recovery is taking place.
(*c*) The pain associated with cystitis and pyelo-nephritis.
(*d*) The pain produced by involuntary spasms.

(*a*) *Root pain.* The subjective pain may be of great severity ; it is fortunately far less common than the text-books would lead one to suppose, and is apt to subside spontaneously. It is usually cited as one of the indications for laminectomy in these cases. Should operation be undertaken with a view to relieving such pain, the nerves affected must be most carefully defined beforehand, and the corresponding intervertebral canals opened up so as to enable the posterior root ganglia to be identified, examined, and if necessary excised. In a clean case the theca, exposed by a generous laminectomy, may be opened, the cord examined, and the affected roots divided on the central side of their ganglia.

The pain elicited by the gentlest stroking of a hyperæsthetic area may be of extreme severity. The suffering occasioned even by contact with the clothing may be so acute as to warrant operation for its relief. This should be upon the same lines as those indicated for spontaneous root pain.

(*b*) *Central pain.* Continuous dull aching pain, disturbing rest, preventing sleep, and causing much distress, is seen chiefly in cases of concussion of the cervical cord, especially during the earlier weeks of recovery. It is referred to the periphery, usually to the hands. As recovery proceeds the pain gradually diminishes. The condition of the cord in these cases —swollen with œdema, minute hæmorrhages, and cavitation—suggests that an incision into it would relieve the pain. In most cases the risk of infecting the membranes is too great to permit of the operation being justifiable ; and on the other hand the prospect of spontaneous recovery is so good that one would hesitate to interfere. On one occasion the pain being so severe, and the wound—a bullet wound—so clean that we were tempted to operate, the cord was incised and the tension was obviously relieved, but unhappily the patient died under the anæsthetic. This experience did not encourage us to repeat the experiment upon

a similar case under observation at the same time ; this second patient eventually went back to duty.

(*c*) The pain of cystitis is in some instances extremely distressing, and has been noted more especially in cases of injury to the cauda equina. The bladder may be small and extremely irritable ; the frequent desire to micturate and the short period of relief afforded by catheterization soon wear the patient down. These are amongst the cases for which supra-pubic drainage is most needed.

2. **Spasticity.** Involuntary spastic movements of the legs may commence at almost any time after the period of spinal shock is over. They may be severe and frequent, causing disturbance of sleep and much distress. These spasms may occur in the abdominal muscles as well as in the legs. Voluntary power may be present, but its degree is masked by the spasticity; such voluntary power serves no useful purpose for standing or walking, as its exercise is liable to throw the limbs into spastic contractions. As recovery proceeds the spasticity gradually passes off, but it is liable to persist for a long period, and to become permanent as soon as the limit of recovery of the spinal cord has been reached. Permanent shortening of muscles is liable to give rise to deformities unless appropriate steps are taken to prevent, or at least to minimize them.

Spasticity affects muscle groups in varying degree. The adductors often predominate ; in other cases the spasticity of the hamstrings is the most marked feature. The knees may be held rigidly in extension, or on the other hand they may evince an almost uncontrollable tendency to become flexed, in which case the tibia is liable to become displaced backwards upon the femur, so that it becomes impossible to straighten the legs. The ankles are sometimes fixed in dorsiflexion. The toes too assume a position, usually of flexion, which may interfere with the usefulness of the foot, should enough recovery ultimately be obtained to enable the patient to walk.

Operative Treatment of Spasticity. When, as frequently happens, the spastic condition affects predominantly the adductor muscles, relief can be given by the comparatively simple procedure of crushing the obturator nerves. By this means the muscles are paralysed for a period of about six months. We have performed the operation in various ways, and have come to think that the following method is the best : An incision about three inches long is made through the anterior rectus sheath just above the pubes ; the muscle is either split in the direction of its fibres, or is drawn bodily inwards. The transversalis fascia having been opened, the finger is passed downwards in the extra peritoneal tissue until the obturator membrane is felt. It is then an easy matter to feel the small hole in its upper part through which the obturator vessels and nerve leave the pelvis to reach the thigh. If the edges of the wound are

now well retracted and a headlight is employed, the obturator nerve can readily be seen. It should now be separated from the artery and veins, and crushed between the jaws of a strong pair of artery forceps.

This little operation is repeated on the other side, and the wounds are sutured like any ordinary abdominal wound.

We have found it difficult to approach both obturator nerves through a single median incision.

The treatment of spasticity of the other muscle groups is more difficult. On the theory that it is due to uncontrolled or improperly inhibited reflex action, the afferent side of the reflex arc may be attacked. By diminishing the number and intensity of the afferent stimuli passing up from the skin, muscles, and joints, the reflex spasticity of the muscles may be lessened without interfering with any voluntary power which may exist; indeed, such voluntary power is brought into prominence.

The operation based upon these ideas is that of division of the posterior nerve roots corresponding segmentally to the spastic muscles and their overlying cutaneous coverings. We prefer to divide these roots where they are lying close together just below the conus medallaris. The laminal arches of the 12th thoracic and 1st and 2nd lumbar vertebræ are removed, and the theca spinalis opened. The difficulty is to identify the individual lumbar and sacral nerves. We have found that a satisfactory method is to identify the 12th thoracic nerve by following the line of the lower border of the last rib backwards. From this downwards the bundles composing the different lumbar and sacral posterior roots can be approximately identified. For general spasticity of the whole lower limb, we divide alternate bundles, commencing with the first lumbar, taking special care to preserve the first sacral in order to avoid the disability in walking which may otherwise be occasioned by diminishing or abolishing the cutaneous sensibility of the sole of the foot and heel. After dividing the roots previously determined upon, the theca is sutured and the wound closed.

Operations such as tenotomy for the rectification of deformities may be required, but if proper splinting is employed from the beginning, the need for these will seldom arise.

In injuries of the cauda equina, where some muscles escape whilst others remain paralysed, the transplantation of tendons is sometimes called for.

3. **Bed-sores.** These are liable to occur in spite of the utmost care in nursing, particularly during the stage of spinal shock. Nevertheless, this is a largely preventable complication, and on the whole the best attended cases suffer least in this respect. The avoidance of hot bottles, of contact with rough blankets, of wetness of the skin, and of pressure upon the sacrum, the hips and the heels, counts for much in preventing bed-sores.

A water-bed filled neither too loosely nor too tightly is essential, and rings of soft wool must be employed to prevent harmful pressure upon bony prominences. The skin must be frequently washed with alcohol, and kept scrupulously dry and clean; sheets must be soft, dry, and free from creases. Frequent slight changes of posture also help by distributing the pressure.

An established bed-sore calls for the most scrupulous care and cleanliness. Sloughs separate with difficulty, and healing is a tedious process. When sloughs exist and much discharge is present, wet dressings are indicated; the addition of an antiseptic, like chlorinated soda, helps to keep down putrefaction. When the slough has come away, an ointment such as 'scarlet-red' ointment is useful.

General Treatment. The paraplegic patient is too often regarded as so hopeless a case that treatment is not carried out with as much keenness as is shown in other and more promising cases. Yet much can be done for him which well repays the doing. The patient's happiness and prospects of recovery depend largely upon his keeping up a high level of general health, and for this purpose not only must all sources of toxæmia be guarded against, but he must be encouraged to obtain exercise by the use of all those muscles which are under his voluntary control. He should not be kept too long in bed, and while there should be allowed to move himself about with his arms and the help of a rope hung from a standard above his head.

It should be remembered that the control of involuntary spastic movements and the recovery of voluntary movements can only be attained by the efforts of the patient himself, and pains should be taken to make him understand that more depends on himself and his exertions than on the manipulations of others. The masseur should devote as much time to making the patient carry out voluntary movements against resistance as he does to actual rubbing.

In patients who are recovering power, there is a period when they can carry out most movements of their lower extremities, but without sufficient power to enable them to walk. It is at this stage that a swimming bath is so valuable in helping the patient to regain power. In the water he is able to obtain ample exercise without being obliged to support the weight of his body. Swimming, too, is an admirable form of exercise and recreation for men who are unable to move their legs and have no hope of regaining that power. The bath need not be large, but the water should be kept at a temperature of about 94° F.

If a swimming bath is not available much can be done by the use of walking machines and self-propelling chairs to enable the patient to keep up his health and to regain some feeling of independence.

LAMINECTOMY IN SPINAL INJURIES

The whole question of operating upon cases of gunshot wound of the spine is so beset with difficulties that we feel it unwise, even after an experience extending over four years, to make any definite generalizations. It may be useful, however, to set out the views which we hold at the present time.

Let us ask, in the first place, whether an operation can in any way influence or assist recovery in the spinal cord. The answer to this question must depend upon an appreciation of the nature of the spinal lesions caused by gunshot wounds. These have been referred to above. Arguments which apply to injuries of the peripheral nerves do not hold good where the spinal cord is concerned, for no regeneration ever takes place in the cord of nerve elements which have been anatomically divided or destroyed. In the case of wounds involving the lumbar spine below the termination of the cord, the nerve elements which may have sustained injury are nerve fibres comparable with those in a peripheral nerve—at least in the case of the motor roots. For the purposes of the present argument we therefore exclude lesions of the cauda equina.

When the spinal cord itself is injured, the lesion is produced at the moment of impact of the missile, and it is rare to find symptoms indicative of progressive involvement of the cord coming on after the date of the wound. In a few cases of concussion of the cervical cord this has been noted, but in the great majority of cases the full degree of damage to the cord is produced by the impact of the missile. In so far as nerve cells and nerve fibres are destroyed, the lesion is permanent, and the only recovery which is possible concerns those cells and fibres whose function is temporarily suspended owing to concussion or œdema. We know that these concussion changes can be, and usually are, recovered from spontaneously, but it is hardly conceivable that any surgical operation can influence their recovery. Whether a decompressive operation performed immediately after the injury would be likely to have any good effect is a matter of theoretical rather than practical interest, for the state of the patient, the circumstances in which the operation would have to be done, and, above all, the septic character of most of the wounds, would usually forbid the experiment.

It becomes, therefore, a matter of great importance to decide how far continued pressure upon the cord by hæmorrhage, fragments of bone and retained missiles, actually plays a part in these cases. Our experience coincides with that of Roussy and Lhermitte that such compression is an uncommon event. We have never seen hæmorrhage producing pressure upon the cord or theca.

From the point of view of the spinal cord, therefore, it appears that

operation could very rarely accomplish anything directly influencing recovery. Further, many of these patients are, on other grounds, unsuitable subjects for operation: they often suffer severely from shock, although this in itself would not preclude the possibility of performing an operation because, by modern methods of 'resuscitation' a severely shocked patient can very quickly be brought into a condition in which he could sustain the operation. In many cases there are other complications which contra-indicate an operation upon the spine; most frequently these take the form of thoracic injuries, sometimes of abdominal injuries, and sometimes of severe wounds elsewhere. So far, then, it is clear that the only cases which, from the point of view of benefiting the spinal cord, are suitable for operation are those of incomplete lesion of the cord, where continued pressure plays a part, and where the patients are in other respects suitable subjects for the operation. Judged by these standards, the number of suitable cases is extremely small.

We may, however, regard these patients from another point of view, namely, that of the wound. As with wounds in any part of the body, it is a matter of importance to secure healing at as early a date as possible, and so to prevent septic complications.

Laminectomy, therefore, might be looked upon as a measure for securing an early and uneventful healing of the wound. Here again, however, the number of cases which is judged, even on these grounds, to be suitable for operation is greatly diminished when we exclude those wounded by rifle bullets. In a series of 215 cases observed by one of us with Gordon Holmes, no fewer than 132 had been wounded by rifle or machine-gun bullets, and in the great majority of these cases the wounds were clean perforating wounds which were clinically aseptic, or at least of such a low degree of septicity as to require no active surgical treatment.

There is still another point of view upon which arguments for and against operation may be based. When fragments of bone, missiles, and blood encroach upon the lumen of the spinal canal, the subsequent cicatrization may be so extensive as to produce effects capable of impeding recovery. It is clear that the more normal the conditions in which cord and membranes can be left, the less likely is the formation of fibrous tissue to be extensive enough to hinder recovery.

The periods at which laminectomy might be performed are three in number:

1. Within a few hours of the injury, and before the growth of bacteria has rendered the wound seriously septic.

During this period an attempt might be made to excise all damaged and infected tissue, and to secure primary healing. Complete excision

of the track would, however, in the majority of cases be impossible on anatomical grounds.

2. An intermediate period, when the wounds are definitely suppurating.

At this stage the only operations which would be justifiable, except in special circumstances, are those directed to the opening up and drainage of the wound. At this stage there is a very considerable danger of setting up meningitis by the removal of spicules of bone which may have penetrated the theca but at the moment are closing the perforation and preventing the escape of cerebro-spinal fluid.

3. At a later date, when the wounds have healed.

Whilst the operation can be done with safety as regards sepsis at this stage, it does not often reveal any condition that can be benefited. Nevertheless such conditions do exist, and, such is the state of these patients, that if an operation holds out any prospect whatever of improvement, it should be done.

(*a*) Adhesions between the membranes and the cord may of themselves form a veritable stricture around the cord or the cauda equina.
(*b*) Bony fragments may be found embedded in scar tissue, lying in close proximity to the cord, possibly impeding its blood supply.
(*c*) Adhesions between the pia and arachnoid may have determined the formation of a circumscribed collection of fluid under pressure; possibly the prevention of the free circulation of the cerebro-spinal fluid in these cases may be of importance. This condition is analogous to that of the 'meningitis circumscripta serosa' of Horsley.

Special Indications for Early Operation.

(*a*) The leakage of cerebro-spinal fluid, in our opinion, calls for immediate operation. Charters Symonds (*Bradshaw Lecture*, 1916) says: 'Should the dura mater be found punctured, or cerebro-spinal fluid escape, no grave consequences need ensue.' This is entirely contrary to our experience, which has led us to regard a cerebro-spinal fistula as a most fatal complication. For this reason we advise operating upon these cases in order to close the hole in the theca and stop the leakage. For this reason, too, we deprecate laminectomy in the presence of a wound in which sepsis is firmly established, lest the theca be opened by the removal of a fragment of bone that may be occluding a hole in it.

The most usual lesion of the dura is a vertical slit, which lends itself readily to suturing. Inasmuch, however, as the suture itself, passing

through the thecal wall, may act as a conductor of bacteria to the membranes, this is not, perhaps, the best method of closure. We prefer to lay over the opening a very thin slice of clean muscle, just as one closes a rent in a bleeding sinus (Horsley's method).

(*b*) When a good stereoscopic radiogram shows a missile to be lying wholly or partly within the spinal canal, in a case where evidence of some conductivity still persists in the cord, laminectomy is indicated, for in such a case it is possible, or even probable, that pressure exists which can be relieved. It is our rule to perform a generous laminectomy, so that the exact state of affairs can be ascertained by inspection, and, as far as possible, rectified. The intact dura should never be opened in the presence of an unhealed wound, however great the temptation may be. If the intrathecal pressure is judged to be excessive, relief can easily and safely be given by lumbar puncture. Apart from the deliberate incision of an unopened theca, nothing is more to be deprecated than the removal of missiles and bony fragments from the neighbourhood of the cord through an inadequate opening.

(*c*) Persistent and intolerable pain from involvement of spinal nerves. This has already been dealt with under ' Pain '.

PURELY FUNCTIONAL AND REFLEX DISABILITIES IN THEIR RELATION TO ORTHOPÆDIC SURGERY

BY

J. LE F. BURROW, M.B. (Edin.), M.R.C.P. (Lond.), Captain R.A.M.C. (T.F.)

Officer in charge of the Neurological Department, 2nd Northern General Hospital, Leeds

AND

WM. CUTHBERT MORTON, C.B.E., M.A., M.D. (Edin.), Lieut. R.A.M.C.[1]

Officer in charge of the Re-education Department, 2nd Northern General Hospital, Leeds

[1] J. le F. B. is responsible for the section on diagnosis and the special note on the treatment of physiopathic cases. The rest is the work of Wm. C. M.

PURELY FUNCTIONAL AND REFLEX DISABILITIES IN THEIR RELATION TO ORTHOPÆDIC SURGERY

I. ORGANIC AND PURELY FUNCTIONAL DISABILITY

In the late war men were every day becoming disabled. In one way and another they lost the power to do something depending upon the proper and co-ordinate contraction of muscles normally under the control of the will. One man became unable to speak, another to walk, a third to close the hand, and so on. In many cases the disability was wholly due to some disease or physical injury which had caused an actual lesion of the ' organs ' upon which the power or function depended. Thus the power to extend the knee is lost if the quadriceps muscle is hampered or paralysed by an ' organic ' lesion such as stiffness of the joint or division of the anterior crural nerve. In other cases the most careful clinical examination could detect no lesion sufficient in itself to have given rise to the disability. Thus a man's foot may drop and become inverted, although apart from this ' purely functional ' disability the limb appears to be perfectly sound.

Purely functional disabilities are often associated with organic lesions which may or may not in themselves be disabling. Thus a purely functional wrist-drop (Fig. 134) may accompany a lesion of the arm which, however severe in itself, is causing no organic disability either by interfering with the musculo-spiral nerve or otherwise. In one case a purely functional flaccidity of the whole upper limb accompanied a wound which by its scarring caused gradual constriction of the musculo-cutaneous nerve. While the purely functional disability was being rapidly cured the organic paralysis of the biceps gradually developed. An operation undertaken for the removal of a foreign body revealed that the nerve was caught in the contracting connective tissue of the deep scar.

Purely functional disabilities are so often hysterical that ' functional ' has come to be a term of reproach. This is unfortunate since, although every hysterical disability is purely functional, purely functional disabilities are often anything but hysterical.

II. LESIONS WHICH MAY GIVE RISE TO ORGANIC DISABILITY

The lesions which may interfere with the proper and co-ordinate contraction of the muscles are innumerable. This is not surprising, since the action of the muscles depends upon (*a*) the *skeletal system*, upon

which they are specially designed to act; (*b*) the *neuro-muscular system*, of which they themselves form part and by which they are controlled; (*c*) the *vascular system*, by means of which they receive their nutrition and get rid of their waste products; (*d*) the *soft tissues in general*, upon whose laxity their freedom of action depends.

III. VARIETIES OF ORGANIC DISABILITY

Organic disabilities are so numerous and varied that it would be unprofitable to attempt to describe or classify them here. It should,

FIG. 134.—Purely functional wrist-drop.

however, be mentioned that reflex disabilities and particularly those of the type which Babinski has termed 'physiopathic' are to be regarded as primarily organic rather than purely functional.

IV. MODE OF PRODUCTION AND CONTINUANCE OF PURELY FUNCTIONAL DISABILITIES

Every purely functional disability is probably produced and kept up by many influences. The intellect, emotions, and will may all be at fault, and usually there has been some kind of trauma even where there may be no evidence of an actual lesion.

The numerous influences which combine to produce and prolong purely functional disabilities are most conveniently studied separately even at the cost of some overlapping.

(i) **Malingering.** It might well be supposed that among the purely functional disabilities of active service there would be many cases of malingering, yet the more disabilities one treats the less is one troubled

by any such suspicion. Often no doubt the man would do better if his will were acting more strongly, but his will is subservient to his emotions and intellect, and he is seldom much to blame for its lowered tone or actual quiescence.

(ii) **Hysteria.** ' Orthopædic cases ' suffering from purely functional disabilities are seldom hysterical.

(iii) **Muscle-habit.** Some authorities appeal to ' suggestion ' in order to explain the onset, form, course, duration, and cure of every purely functional disability. Now, however great the influence of ' suggestion ' may be, many a purely functional disability can be simply and naturally explained as a muscle-habit initiated by organic causes and maintained chiefly by a mistake on the part of the patient in that he never realizes that it can be cured, still less that he can cure himself. Even if suggestion can never be proved to have been absent, and even if the disability can be cured by suggestion and persuasion, this is no proof that these are responsible for its onset and continuance, nor need it in any way be a reproach to the man since these influences are responsible for most of the mistakes and habits, good, bad, and indifferent, in life.

(iv) **Trauma.** A trauma may be the starting-point of a hysterical disability or lead to a bad muscle-habit, or it may set up a reflex disturbance.

(*a*) The immediate effect of a trauma is often some loss of power and sensation due to local injury or shock. This disability which is really organic may soon pass off, but it is often prolonged as a purely functional flaccidity. The trauma may be disregarded at the time in which case the disability is delayed some hours, days, or even weeks, when it may suddenly or gradually develop if the general tone of body or mind has through any cause been sufficiently lowered. Sometimes a purely functional disability follows an operation. Thus, a man was wounded in the buttock, and when the shrapnel was removed by operation about three weeks later he became unable to walk without crutches owing to spasm of the quadriceps, and flaccidity of the rest of the limb originated perhaps by reflex nerve irritation. In this connexion it may be noted that the quadriceps is often flaccid even where it might not at first be suspected. In every case of drop-foot the whole limb should be carefully examined for weakness of the muscles of the knee and hip with down-tilting of the pelvis on the other side and corresponding scoliosis.

(*b*) A purely functional inco-ordination may be the result of the orderly recovery of an organic nerve-lesion, a result which persists after the lesion itself has recovered, simply because the man does not know that he can be cured, still less that he can cure himself. Thus a man received a bullet wound which injured all the cords of the brachial plexus, and especially the inner cord, so that the nerve-supply to the muscles of

the fingers was interfered with and especially that to the flexors. The order of recovery would thus be first the extensors, then the long flexors, and lastly the interossei. Now when a part is disabled the effort to overcome the disability commonly results in all the muscles of that part, and sometimes those of other parts also, being simultaneously called into action even although their action is to antagonize one another. When therefore in this case the flexors began to recover, the effort to flex brought into play the more powerful extensors, and since these were acting chiefly on the first phalanges while the interossei were not yet able to extend the second and third, the effort at flexion resulted in a faulty closure of the hand by extension of the first with flexion of the second and third phalanges. When at last the interossei gradually recovered they had to give way before the long flexors, which were themselves overpowered by the extensors. This inco-ordination was therefore in its onset organic, and it persisted through sheer force of habit, since the man failed to realize that he could close his hand perfectly if only he would set about it in the right way. No doubt he responded to the strong suggestion afforded by the severity of the injury which had originally disabled him, but there is no need to suppose that he was either malingering or hysterical. After a nerve has become organically paralysed, the man who never tries will have his muscles always relaxed, so that as the nerve gradually recovers he may easily fall into the proper co-ordination; whereas the man who is more eager for a rapid recovery is apt to try so vigorously that he brings the unparalysed antagonists into play, so that at first, when there is no counter-tension, he does precisely the opposite of what he is attempting, and later, as the paralysed muscles gradually recover, he uses the unparalysed antagonists with ever-increasing vigour, and the harder he tries the less possible is it for him to succeed. In re-educating such a case as the above absolute voluntary relaxation is the first essential, and the only exercise then required is flexion of the phalanges of the four fingers together in due succession, namely, first, second, and third (Fig. 135).

(*c*) Any trauma which disturbs the normal mechanism of the muscles may lead to a purely functional disability. Thus a man received a perforating wound through the knee-joint which caused an organic limitation in extension. Partly perhaps to avoid pain in the knee itself, partly no doubt in order to compensate for the shortening of the limb, he fell into the habit of walking on the toes of that side. As the limb became straighter and therefore longer, instead of compensating for the increasing length by bringing the heel to the ground he appears to have found it more comfortable to tilt the pelvis upwards on that side. Even after complete extension of the knee became possible he still walked on the toes with the pelvis uptilted, but when the origin and mechanism

A

B

C

D

E

Fig. 135.—(*A*) Closure of the hand by extension of the first and flexion of the second and third phalanges.

(*B*), (*C*), (*D*), (*E*), Positions of the hand in successive flexion.

of the disability were explained, and he was put through appropriate exercises, he rapidly overcame the disability. It is not enough to impress upon such a patient how easily he can be cured if he will only set his mind to it. He will take it much more to heart if he is shown just how the bad habit arose and how it may be cured.

(*d*) A wound which gives no evidence of itself may have caused an organic disability which persists in a purely functional form. Thus a man may have had a severe injury to the ankle giving rise to an organic foot-drop with inversion which persists as a purely functional disability. If he has been buried by an explosion, or has been unconscious, or very ill, he will naturally be all the more firmly convinced that his disability is serious and unlikely to be cured, yet with training he may rapidly improve.

(v) **Pain.** Pain is important because it is so frequent and so disabling, because it is often due to some organic condition which can hardly be detected, and because in some cases it can be removed by surgical or other means. A man has a painful scar on the inner side of the sole in consequence of which he walks on the outer border of the foot. In time the evertors become flaccid, and although re-education may succeed in restoring good voluntary eversion, relapse is certain unless the pain can be removed.

(vi) **Anæsthesia.**

(*a*) *Organic Anæsthesia.*—When a part has become anæsthetic owing to an organic lesion, the control of the muscles may be interfered with by the loss of the sensory impulses from them, and this disability may be exaggerated because the man is under the impression that the muscles in the neighbourhood of the cutaneous anæsthesia are necessarily paralysed. Thus, if the ulnar nerve be divided just above the wrist the motor nerve-supply to the short muscles of the fingers is cut off and there is much cutaneous and deep anæsthesia in the palm. If the long flexors have been temporarily affected by the organic injury a purely functional disability may persist because the man is still unable to feel the effect of their contraction in the hand. One of the effects of anæsthesia is that the part feels very heavy, and this no doubt accounts to some extent for the profound flaccidity in many cases of drop-foot. There is little inducement to try to raise the foot if it feels unduly heavy, and if, when the muscles do pull, their contraction gives rise to none of the muscular sensations proper to the movement.

(*b*) *Anæsthesia of Disuse.*—There is another type of case in which, without any organic anæsthesia, a purely functional disability may be produced and continued. A man is severely wounded, and owing to fracture with complications, the limb is kept quiet for many months. This is done mechanically by means of splints, but at the same time the

patient is instructed not to move the limb so that he ignores all reflex stimuli and suppresses all voluntary impulses. For many months, therefore, the muscles do not once contract, and so the sensory nerve-endings within the muscles and their tendons are never once stimulated. The muscles are, in fact, in a condition resembling sleep. When finally the splints are taken off and the limb may now be moved, the muscles can only be made to contract by order of the higher centres. But these centres depend for their knowledge of the muscles on the sensory nerve-endings which remain quiescent until the tension within the muscles is varied by their contraction. The muscles must, therefore, be waked by both external and voluntary stimuli. For this purpose massage and simple passive movement are not enough. Nor should too much reliance be placed upon voluntary effort alone, however important this is in itself. Every means should be employed to stimulate reflex contraction of the muscles so as to restore the muscular sensations on which voluntary control depends. Electricity has the disadvantage that it masks these sensations.

There is reason to believe that any muscle which is ignored or suppressed may in time pass beyond the control of the will, possibly because it has become anæsthetic through disuse. Thus, if in using the hand the second phalanx of the thumb cannot be flexed (as for example when its tendon has been severed), the extensor may become completely flaccid. Again, when the middle finger has been injured so that it can no longer be fully flexed, the deep flexor of the fingers is so hampered that even its bellies to the uninjured digits do not contract properly, with the result that the hand cannot be closed because the terminal phalanges cannot be fully flexed (Fig. 136). Since almost the only duty of the deep is to co-operate with the superficial flexor in securing complete closure of the hand, it is not surprising that when this cannot be done the muscle should become flaccid. Such a physiological law governs other functions of the body. The brain ignores an alarm clock if its stimulus has not been regularly heeded. The rectum ceases to call if its call has not been regularly obeyed. The stomach stops craving for food if food has been too long withheld. (It may be noted in passing that in most people, if the middle finger be held passively extended and the hand be now smartly closed a shooting pain is felt in the flexor region of the forearm, due perhaps to contraction of the belly of the deep flexor without shortening. Both the imperfect closure of the hand and the pain in the forearm are also frequently found though not always so marked where some finger other than the middle has been injured or is being held.)

(vii) **Gravity.** Gravity may make it more difficult for a muscle to contract or even to retain its tone. Its action is well seen in wrist- and foot-drop, in which, apart from the feeling of excessive weight not uncom-

mon in paralysed limbs, a considerable weight is actually thrown upon the paralysed muscles so that they are stretched. In purely functional disabilities the muscles should be kept almost as carefully relaxed as in disabilities due to organic nerve lesions. For this purpose sling cock-up splints (Fig. 137, A and B) have been devised for flaccidity of the supinators and the extensors of the forearm and hand, and a chain eversion support for drop-foot with inversion (Fig. 138). In drop-foot with inversion the evertors (long and short peronei) are flaccid. As to the flexors of the ankle and the extensors of the toes the *anterior tibialis* may be normal,

FIG. 136.—Injury to the middle finger with organic limitation in flexion of the terminal phalanx leads to organic limitation in flexion of the terminal phalanges as seen in the figure, and in this case there was also a purely function limitation shown by the fact that if the first and second phalanges of the index, middle, and little fingers were passively held extended the terminal phalanges could not be flexed.

flaccid, or in tonic spasm, the *extensor of the hallux* is sometimes flaccid, the *long extensor of the toes* is usually extremely flaccid and difficult to rouse, the *third peroneus* varies, while the *short extensor of the toes* may be pulling although all the others are flaccid. The comparative immunity of the short flexor of the toes is perhaps accounted for by the fact that it has not been stretched by gravity since it arises below the ankle and there is no flexion of the toes. On the same principle the frequent and profound flaccidity of the long extensor of the toes might be explained by its being particularly liable to stretching. It is interesting in this connexion to note how often one or both of the terminal branches of the musculo-cutaneous nerve stand up beneath the skin like fine cords. Where the stretching is excessive or unduly prolonged a muscle may become organically disabled.

V. VARIETIES OF PURELY FUNCTIONAL DISABILITY

Purely functional disabilities may be classified as follows :

(i) **According to the part involved or the function lost or the attitude which results.**

A

B

FIG. 137 (A and B).—Sling-splint—long skeleton cock-up. Any degree of supination can be readily obtained. Gravity keeps the wrist extended so that bandages can be dispensed with, and the limb is freely exposed to the air. There is no pressure on the extensors, since the forearm rests on its ulnar border, and the straps crossing the forearm check all movement without pressing when the limb is at rest. The splint cannot without a deliberate effort be pronated, on account of the long upright metal bar which rests against the chest. The hand can be removed from the splint, freely used, and replaced with the greatest ease. The splint has been found very useful in recovering musculo-spiral lesions complicated by a functional element.

These varieties are innumerable. Thus in wrist-drop the hand cannot be extended, in tilting of the pelvis the muscular balance between the two sides is lost, and so on.

(ii) **According to the condition of the affected muscles.**

In one and the same disability the condition of the muscles may be very different. In general the muscles may be regarded as being arranged

in antagonistic groups such as flexors and extensors, as in the case of the elbow. Normally both groups when at rest are in slight tonic contraction and when movement takes place one group relaxes while the other increases its pull. A purely functional disability consists in the derangement of this mechanism.

(A) *Flaccidity.*—Sometimes the disability is due to underaction (flaccidity) of either or both groups. In such a case passive movement

FIG. 138.—Chain support for drop-foot with inversion. In certain cases, but by no means all, the chain works better if it is attached to a single upright on the inner side, or again two uprights may be needed, one on each side. The chain may be fitted with a spring. This eversion of the forepart of the foot has been found useful in recovering organic and even in purely functional drop-foot with inversion.

is free whereas active movement is possible only in a group which has retained its tone, and even this movement may not be good owing to the loss of tension in the antagonists. Thus, in flaccid wrist-drop, there may be very poor flexion of the fingers.

(B) *Spasm.*—At other times there is spasm of either or of both groups.

(1) *Persistent or Tonic Spasm.*—In tonic spasm the muscles pull and refuse to let go, so that if the spasm is marked active movement is impossible and passive movement difficult and painful. Thus in one case

the biceps was in tonic extension for over two years, and in another case the triceps for one year (Fig. 139). Flaccidity and tonic spasm may both be present in different members of a single group or even in different groups. Thus the knee may be in tonic extension while the rest of the limb is flaccid (Fig. 140).

FIG. 139.—Tonic extension of the elbow following fracture of the lower end of the humerus. Note the loss of the carrying angle. Cured in one sitting.

FIG. 140.—Tonic extension of the right knee with flaccidity of the hamstrings and of all the muscles in the leg and foot. Functional element cured in one sitting.

An interesting point about these purely functional disabilities is the frequency with which they correspond to a definite nerve distribution, although the degree of overaction may vary in different parts. Thus (*a*) Fig. 140 represents an overaction of the anterior crural and an underaction of the sciatic nerve. (*b*) Fig. 141 represents a moderate overaction of the ulnar nerve below the long flexor (profundus), as shown by the adduction of the thumb, the extension of the first with flexion of the second and third phalanges of the fingers,

and the opposition of the little finger. (*c*) Fig. 142 represents overaction of the ulnar and median nerves (about the level of the wrist flexors) in which the long flexors have overpowered the intrinsic muscles of the hand.

FIG. 141.—The 'accoucheur's hand', caused by spasm of the intrinsic muscles of the hand supplied by the ulnar nerve. The thumb is adducted, the little finger adducted and opposed (?), and all the fingers flexed at the first and extended at the second and third joints. The long flexors do not come into play. Contrast this with Fig. 142.[1]

FIG. 142.—1. Tonic flexion and adduction of the thumb. 2. Closure of the hand by extension of the first and flexion of the second and third phalanges: the long flexors have overpowered the intrinsic muscles of the hand supplied by the median and ulnar nerves. Contrast this with Fig. 141.

(*d*) Again the 'swan's neck' hand (Fig. 143), although usually regarded as typically hysterical, can be explained by an overaction of the median and ulnar nerves. Overaction of the anterior cords, if complete, produces adduc-

[1] It was only recently that it occurred to the writer that tonic postures might perhaps be explained along anatomical lines. He is indebted to Sir Harold Stiles for the example shown in Fig. 141, and there may well be yet others.

FIG. 143 A.—Reflex spasm of the flexors of the wrist, interossei, and adductor of the thumb, after a gunshot wound of the forearm. 'Swan's neck' hand, (incomplete).

FIG. 143 B.—The same case after training.

tion of the shoulder, flexion of the elbow, pronation, and flexion of the wrist, which last, if it is marked, places the long flexors of the fingers at a disadvantage and prevents the long flexor of the thumb from functioning at all. The intrinsic muscles of the hand therefore get full

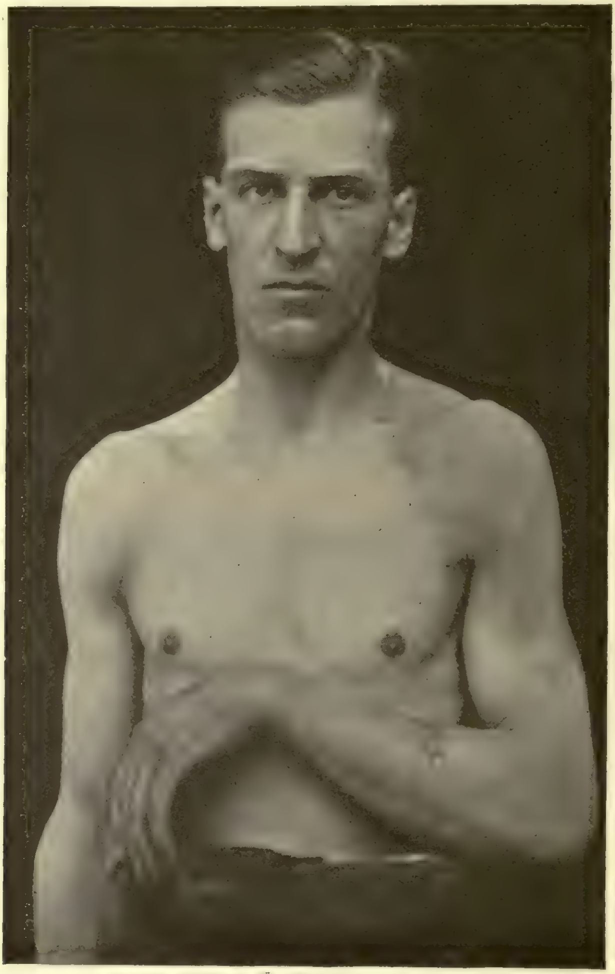


FIG. 144 A.—Tonic adduction of the arm and flexion of the elbow, following retention of the limb in a sling after a wound of the scapula. A piece of shrapnel located in the supraspinous fossa caused considerable pain.

play, so that the thumb and little finger become opposed to each other, the index, middle, and ring fingers are flexed at the first and extended at the second and third joints, and, since in this position the abductor interossei are at a disadvantage, the adducted index and ring fingers squeeze the medius, which therefore takes the line of least resistance and

slips backwards. The tips of the digits are now grouped as follows: in front, the opposed thumb and little finger, behind these the adducted index and ring finger, and behind and in the groove between these the middle finger. In the upper limb overaction of the muscles of the posterior cord is rare as compared with the anterior cords. In the lower limb, on the other hand, overaction of the anterior crural nerve is common (Fig. 140), but this may be associated with the great part which each quadriceps is

FIG. 144 B.—The same case as 144 A, taken two hours after the first treatment. Afterwards the shrapnel was removed and the pain much alleviated.

called upon to play in raising the whole body, as in climbing. (*e*) Tonic inversion of the foot (Fig. 145) at first sight appears to be an exception, since the tibialis anticus is supplied by the anterior whereas the tibialis posticus is supplied by the posterior tibial nerve. Apparently, however, the whole sciatic nerve is overacting although the dorsiflexors of the ankle and toes are overpowered by the calf muscles and the toe-flexors, while the tibialis anticus is still able to act as a powerful invertor. Fig. 144 A shows flaccidity of the posterior cord muscles with overaction of the anterior cords in their upper reaches. It might be argued that this is the position of comfort, but if a comfortable position is evidence of hysteria, why should a hysteric develop a 'swan's neck' or an 'accoucheur's hand', or a tonic drop-foot with inversion? May not these postures be due to

painless 'cramps' of the muscles coming on when the nervous control is below par, the reflexes disturbed, the physical balance of the muscles themselves upset, and the local circulatory mechanism so deranged that the products of muscular metabolism cannot be sufficiently rapidly

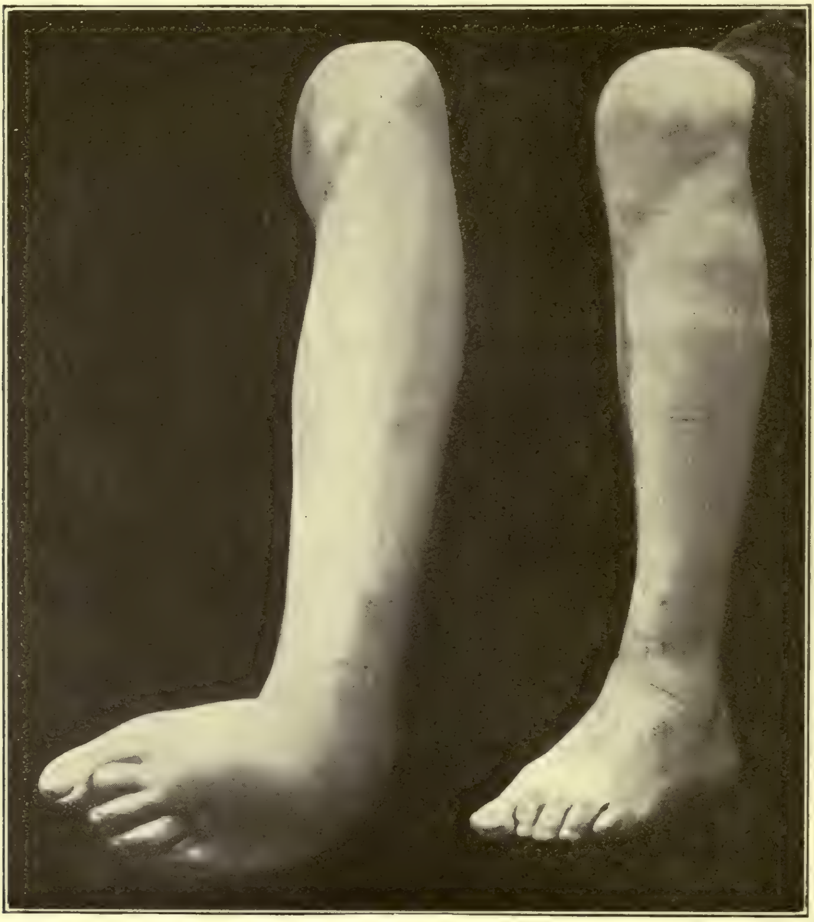


FIG. 145.—(*A*) Tonic inversion of the foot, with œdema of the foot and leg, after gunshot wounds of the leg. (*B*) The same case after training.

removed? In ordinary life a cramp is usually so painful that even at the cost of pain it must be cured at once, on which account it is at once followed by a powerful reflex and voluntary contraction of the antagonistic muscles. Yet even in ordinary life painless cramp sometimes occurs (as for example in the interossei), and although, if left alone, this passes off before long, it is conceivable that under abnormal conditions cramps may be produced which, though not in themselves painful,

cannot be overcome by voluntary effort alone, but require passive movement which, however, causes such pain that the original cramp becomes exaggerated by a super-added contraction, both reflex and voluntary. The curing of such a condition in a few minutes by re-education (including 'suggestion') combined with passive movement would be no proof that the condition was in any way due to hysteria.

(2) *Rhythmical or Clonic Spasm.*—There may be clonus, that is to say, a rhythmical contraction of one or more muscles or muscle-groups or even of most of the muscles in the body. Clonus is sometimes found in a single muscle such as the *posterior tibialis.* Thus in the position of rest the foot may be inverted through flaccidity of the peronei, and the posterior tibialis tonically shortened but not pulling so strongly as to have much influence on the inverted foot. If now the foot be gradually and gently everted the posterior tibialis may be felt contracting almost rhythmically. Clonus is often seen in the *calf muscles.* In such a case if the foot be rested upon the toes and the heel allowed to drop the sudden stretching causes a smart contraction of the muscles of the calf so that the heel is raised. The heel now drops by gravity and once more the muscles contract. Another example of clonus in a single group of muscles occurs in the back. The *erectores spinæ* contract and extend the vertebral column and, when the muscles relax, the elasticity of the ligaments bends the column forward and stretches the muscles again, so that they again contract. So rapidly is this repeated that in one case the clonus was estimated at something like two hundred per minute. In many cases the clonus is due to the rhythmical reciprocal stimulation of *antagonistic groups* of muscles. Thus the flexors by contracting stimulate the extensors to pull, and the pull of the extensors now causes the flexors to contract again.

(3) *Irregular Spasm.* In clonus of two antagonistic groups the individual muscles are so co-ordinated that each group contracts as a whole in response to the stimulus derived from the sudden tension caused by the contraction of its antagonists. In irregular spasm, on the other hand, the muscles are not co-ordinated into groups, and so when any muscle contracts it may be helped or hindered either by the other members of its own group or by one or more of the antagonists, and its action may even be distorted by the deficient or excessive counter-tension caused by the flaccidity or sudden contraction of muscles belonging to quite other groups. Thus in walking not only may the thigh be too rapidly or too slowly flexed according to the condition of the antagonistic flexors and extensors, but it may also be suddenly abducted or adducted and even rotated inwards or outwards. If the action of the knee- and ankle-joints be also irregularly spasmodic the limb will be uncontrollably jerked about in every direction and walking will be impossible.

(c) *Pure Inco-ordination.*—In flaccidity, spasm, and clonus, control of the individual muscles is lost and co-ordination is of course impossible, but there are cases in which control is retained except when an attempt is made to execute a particular movement. Thus in the hand all the muscles may appear to be normal in tone yet it may be quite impossible to close the fingers. Instead of flexing the phalanges in due sequence the first are extended and the second and third flexed. The patient, unaware of the cause of his disability, increases the pull of both groups proportionately with the result that the fingers become more and more rigid. Careful demonstration of the mechanism of this disability has never failed to bring about a rapid cure.

(iii) **According to the cause.**

(*a*) Hysterical.
(*b*) Muscle-habits.
(*c*) Reflex.
(1) Without vasomotor disturbance.
(2) With vasomotor disturbance.

When the vasomotor disturbance is marked there are other features which justify this class being regarded as organic rather than purely functional. It is not possible to draw a hard and fast line between the various types, so gradually do they merge into one another and so closely are they interwoven.

SPECIAL NOTE ON REFLEX PARALYSIS OR PARESIS

[' Physiopathic Contracture ' of Babinski and Froment. ' Acromyotonus ' of Siccard. ' Paralysis from peripheral irritation,' Weir Mitchell.]

Amongst the clinical types commonly classed as ' functional cases ' occurs one with a very definite clinical picture.

A typical history of onset and progress characterizes this class of case, which is best known as ' reflex contracture '.

History of Onset. The patient is usually quite a healthy-minded man, and there is no trace of an exaggerated emotional state. An injury, as a rule trivial in nature, has been received : it may be a simple crush of the foot or hand without fracture, or a simple bullet wound through the soft parts of a limb without damage to important nerves or vessels.

The deformed attitude of the injured limb may be noticed a few moments after the injury.

Usually, however, it is not until the bandages are removed and the patient attempts to use the affected part that he notices his deformity.

The presence of pain or of altered sensation may direct his attention to the part in the first instance. The patient commonly attempts to correct the vicious attitude by voluntary movement, but fails to do so for more than a few moments.

We have known men, who have been discharged from the Army, spend considerable sums from their scanty means in the purchase of various appliances to restore the position of a foot or hand to something like the normal. There is no question of malingering in these cases.

The unnatural position of the limb persists in spite of these measures, and the men are referred or apply personally to one of the special hospitals or other hospital for treatment.

The Appearance of the Affected Limb. In the upper limb the deformity assumes one of a few clinical types.

One common type is that of a markedly exaggerated form of 'drop wrist', a deformity which can be produced only by atony of the dorsiflexors of the wrist and strong contraction of the opposing flexor group. The resulting deformity gives a 'swan's neck' appearance, or as Babinski describes it, like the fore paws of a dog when he squats on his hind quarters to 'beg' for food (see Fig. 143 A). Another common deformity of the hand is a crowding together of the fingers by strong adduction so that the fingers overlap like the tiles of a roof (see Fig. 141). The fingers are slightly flexed at the metacarpo-phalangeal joints and extended at their inter-phalangeal joints and simulate the main d'accoucheur of tetany. In this type the thumb is usually slightly flexed, and is applied to the palm by adduction. A rarer deformity is that in which the wrist is carried in strong dorsiflexion owing to the contracture of the extensor group combined with atony in the flexors. In the lower limb any variety of club-foot may be found combined with a crowding together of the toes. The commonest is varus, either pure or associated with equinus or calcaneus, the ankle being flexed or extended, and either of these positions may be complicated by inversion or more rarely eversion of the foot. In these cases of inverted foot, atony of the peronei and strong contracture of the tibialis anticus and invertors will be noticed. Although attention has been directed to one or two common types, many others occur, and they are all easily recognizable by the presence of the other features of the syndrome. Flexion and extension contracture at the knee-joint or at the elbow-joint are not uncommon. The hip and spine cases form a small percentage.

The Position of Wounds and Scars is to be noted. It will be seen that these are quite out of the track of important nerve trunks or large blood-vessels, and the trivial nature of the wound is usually a feature of these cases. The wound may be remote from the part of the limb which is affected by the contracture.

Appearance of the Skin. The skin is usually cyanosed and cold to the touch. If the parts have been subjected to prolonged immobilization in splints or other apparatus there may be a certain amount of delayed desquamation of the surface layers and changes of the nails with diminished growth, as was noticed by Head and Sherren in cases of simple fracture without nerve lesion. There are never trophic blisters or ulcers. Adventitious bursæ are developed over such areas as the outer side of the foot when the patient walks with his foot inverted.

Vasomotor and Secretory Changes. The limb may be slightly œdematous or simply blue and cold without œdema, the appearance being less pronounced but certainly similar to the ' local asphyxia ' of Raynaud's disease. Local changes in the blood pressure have been recorded by Babinski and Froment, who used Pachon's oscillometer for the purpose. There is frequently, but by no means always, exaggerated sweating over the affected section of limb. As time goes on changes in the bones of the nature of decalcification may be found by means of the X-rays. The hair tends to increase in amount, and the skin loses its natural folds and creases, so that it appears more like the surface of a wax model.

The Muscles. Muscular atrophy is well defined. The degree is distinctly less than that which occurs in lower motor neuron paralysis, and more than that due to simple disuse. The degree of atrophy approaches that which occurs in the muscles about a diseased joint, from which it can easily be distinguished, since only one group or part of a group is affected, while the opposing group are in a state of marked hypertonicity. The contracture of the hypertonic group persists under observation. Active movements in an attempt to correct the deformity are accompanied by some relaxation of the contracted muscles, but these relapse as soon as the patient rests from his exertions. There is no complete paralysis as a rule. Passive movement to overcome the contracture causes exaggerated action in the contracted group, and a clonus may be started by manipulation. The atony and hypertonicity may be realized by palpation of the muscles. The contracture persists, as Babinski and Froment state, until the patient is deeply under a general anæsthetic. The loss of power is not complete in the wasted atonic muscles; a degree of movement can be made out when the hypertonic group are placed purposely at a disadvantage. The feeble action of a wasted group is usually smothered by the violent reaction of the hypertonic opponents, so that in a casual examination it may escape notice.

The hypertonic muscles may correspond closely to a group supplied by a single peripheral nerve, as has been previously noted in these pages, but the whole syndrome of physiopathic contracture cannot be explained upon a basis of organic injury to such a nerve. The combination of an atonic and hypertonic lesion in the same limb, or section of the limb, is

almost characteristic. The hypertonic muscles are in active contraction, so that the condition is much more than the almost mechanical contracture or shortening which takes place in a group of muscles when their opponents are paralysed.

Percussion of Muscles. The affected muscles, if their bellies be sharply tapped with a percussion hammer, give an exaggerated response to this mechanical stimulation, and the resulting contraction is large in amplitude, somewhat slow to rise to its height, and much slower to subside. It is difficult to decide whether these characteristic contractions are due to nervous influences, or are largely caused by the lowering of the local temperature associated with vasomotor changes. After immersion of the affected limb in a bath of hot paraffin wax there are marked changes in the character of the contractions, which become rapid and lose some of their sluggishness.

Changes in Electrical Responses. The reaction of degeneration is never found in the muscles of a case of ' reflex contracture '. There is an exaggerated response to faradism unless the limb be so cold that the skin resistance interferes with the passage of the current.

Stimulation with the galvanic current produces a slow contraction of large amplitude, a response something similar to that associated with R.D. If the affected limb be immersed in hot water and re-tested with the constant current, it will be noticed that the muscle responses are more brisk, and approach to the healthy muscle twitch.

It is possible to obtain slow contractions of small amplitude in the muscles of a healthy limb which has been adapted to cold, so that there is a probability that low temperature and local tissue chemistry may explain the characteristic slow muscle response in these cases.

Reflexes. There is some exaggeration of the tendon jerks in the part affected, though, owing to the attitude of the limb, the responses may be difficult to observe. The exaggeration is often more apparent with the patient under a general anæsthetic just short of abolition of the corneal reflex. The skin reflexes, especially the plantar, may be difficult to obtain with the contractured limb in its usual cold state. True abolition of skin reflexes does not occur. Reflexes not obtained at first will be elicited when the limb is warmed.

Sensory Changes. Pain may be present, but this is usually caused by muscle strain, or due to unnatural strains on ligaments, &c. Hypæsthesia certainly occurs, but follows no nerve or nerve-root distribution on the skin.

Sensory stimuli are usually well appreciated when the affected limb is warmed.

Ætiology. It is not proposed to discuss the theories of causation of this clinical entity at all fully in these pages. The descriptive papers of

Babinski, Froment, Heitz, Vincent, Sicard, Porot, and many others, and for earlier conceptions the works of John Hunter, Weir Mitchell, Charcot, Vulpian, Graves, Brown-Séquard, &c., should be consulted.

Briefly, the contractures and vasomotor state may be explained as due to the efferent influences sent out from the central nervous system in response to afferent messages. The sensory messages in the first days after the lesion may be painful. Much more subtle are the subconscious impulses which may give rise to striking motor and vasomotor effects for which clinical examination reveals no obvious cause, such as a painful scar or pressure upon some sensory nerve by contracting fibrous tissue. The reflex phenomena associated with pain or inflammation will, as we know, cause immobilization of a diseased joint by control of the muscles which act on it. The muscles of the chest or of the abdominal wall are in a like manner controlled when organs which lie beneath or associated with the same spinal segments are diseased. The local rigidity which occurs under these conditions seems to be in some measure allied to the hypertonicity of reflex disorders. In chronic disease the structures become fixed in their new positions, and we are not surprised to find that after a few months our 'reflex cases' do the same, to a lesser extent.

The hypertonic muscles become organically shortened and the over-stretched atonic group become fibrosed. In the joints there is alteration of the normal axes with deformity of the ligaments. Some observers, such as Roussy and Lhermitte, suggest that these contractures are due to psycho-neuropathic causes, and that the vaso-motor disturbance is accounted for by prolonged immobilization. These observers, however, are careful to state that the prognosis is not so good as in the case of hysterical paralysis.

Hurst states that these cases are hysterical, and that they should be curable at a single sitting by the use of psychotherapy. Our experience is that these patients are not cured at once, even by intensive re-education, although the patient may be taught to temporarily correct the contracture at the first sitting. Patients are not regarded as cured until their limbs have regained entirely the healthy attitude.

VI. DIAGNOSIS. GENERAL CONSIDERATIONS

1. **Organic Paralysis of the Spastic or Upper Motor Neuron Type.** The history of the injury and its position, the state of the muscles and reflexes, the nature of the sensory loss, e. g. Brown-Séquard syndrome, will, as a rule, suffice to place the nature and site of the lesions beyond a doubt.

2. **Organic Paralysis of the Flaccid or Lower Motor Neuron Type.** The history of a febrile attack followed by paralysis, or the position and

nature of any injury, together with the extent and type of motor loss will all give valuable evidence.

The atrophic atonic muscles which give a reaction of degeneration to electrical stimulation will point to the lower motor neuron as the site of the damage. The distribution of the motor and sensory loss will exactly localize the lesion as in either the anterior horn of the cord, nerve roots, trunks, or individual peripheral nerves. The state of the reflexes will add confirming evidence.

3. **Hysterical (Pithiatic) Paralysis or Contracture.** The hysterical or pithiatic contracture is usually easy to recognize, so that such patients are rarely referred for orthopædic treatment primarily.

For diagnostic purposes it may be recalled that these cases often present unexpected contractures or paralytic attitudes, the disability being an obvious exaggeration of some organic paralytic deformity, or a quite distinctive type. There may be a history of hysterical convulsive attacks. The contradictory nature of the paralysis, e. g. astasia abasia (inability to use the legs when standing, although the muscles are powerfully used when the subject is lying down).

Above all in the pithiatic case the contracture is very variable. It varies from day to day, and may vary even under examination.

Confirmatory evidence is mainly the absence of signs and symptoms which accompany organic disease.

There are never any alterations of importance in the reflexes. Vasomotor phenomena are never more than a slight coldness of the part from lack of use.

There are no trophic disturbances nor modifications in the electrical reactions of the affected muscles. Finally, the symptoms disappear by the use of unaided suggestion with striking rapidity.

4. **Disabilities associated with Muscle-group Inco-ordination, bad Muscle Habits, &c.** This class of case is entirely functional and may be due to a variety of local conditions. It is recognized by the various features of each individual case and by exclusion of other types of functional disability.

5. **Reflex Contracture.** Fully developed cases of ' reflex contracture ' are diagnosed by the vasomotor changes, muscle atrophy, the presence of atony and hypertonicity in the same segment of the limb, changes in the reflexes, mechanical and electrical hyper-excitability of muscle, and by the persistence of the contracture even under comparatively deep general anæsthesia.

6. **Paresis and Atrophy called ' Arthritic Muscular Atrophy '.** Injuries to bones and joints, especially if prolonged immobilization has been necessary, are apt to be followed by a motor weakness like that seen in ' reflex contracture ', to which indeed this condition is allied.

Where there has been an injury to a joint all the groups of muscles round the affected spot are involved. There is no atonic and hypertonic condition present in the same neighbourhood at the same time.

The muscles give reduced responses to faradization, and there are no sensory changes in uncomplicated cases. The cause of the condition is fairly clear from an inspection of the part.

7. **Deformity associated with painful Scars, &c.** Deformed positions of a limb due to the presence of painful scars, wounds, or other local traumata are common.

In this class of case the patient does not use a group of muscles because a particular movement or joint position is uncomfortable.

A glance at the injured region and gentle palpation will be enough to demonstrate the cause of this disability.

8. **Contracture or Lack of Movement due to Muscle and Tendon Injury.** Many examples of this form of deformity might be quoted, for they are common sequels of large lacerated shell wounds sustained in the present war.

In the healing process of the lacerated septic wounds of muscle much fibrous tissue is developed, and when this consolidates the injured structures it pulls upon all its surroundings. One of the consequences is a shortening of muscles which may, in their turn, pull a joint out of its normal axis. This may be seen in the 'drop foot' with some inversion due to contracture of the muscles of the calf after a large wound in that region accompanied by considerable loss of muscle substance.

Similar deformities may follow the division of tendons, or adhesion of them during the processes of repair after suppuration. Paresis may be due to the over-stretching of muscle during an organic paralysis which has recovered months before.

The local conditions observed to be present and the responses of the muscles to faradic stimulation will distinguish these traumatic cases at once.

9. **Traumatic Contracture (Littlewood) sometimes called 'Volkmann's Ischæmic Paralysis'.** This condition is fully dealt with elsewhere, so that the subject is discussed here merely as it affects the diagnosis of functional paralyses, &c.

In these cases there is usually a history of fracture or of vascular injury, which may have been followed by a surgical operation to arrest hæmorrhage from the important blood-vessels at the root of a limb.

The patient will often describe how the whole limb became swollen, intensely painful, and afterwards paralysed. Usually we see the later stages of the lesion in orthopædic cliniques. The appearance of the limb is characteristic. There are contractures in all the peripheral joints. The skin is atrophic and often broken by trophic ulcers. The cyanosis

and coldness of the part become more marked towards its extremity. The pulses are not palpable in the peripheral arteries, and even main arteries give a feeble impulse. There is muscular atrophy which follows no definite nerve supply: all the peripheral muscles are atrophic, and to the touch feel like the masses of firm fibrous tissue that they have in reality become.

The sensory loss is profound, and again follows a glove or stocking type rather than the area of any root or nerve distribution on the skin

Electrically in the early stages the muscles may respond to both the faradic and the galvanic current, whereas in the later stages they respond to neither.

All contractility, both to mechanical and electrical stimuli, is gradually abolished as the fibrous transformation of the muscles advances.

Cases with a combined vascular and nerve lesion, especially if the latter present symptoms of irritation syndrome, may be difficult to distinguish from traumatic contracture.

10. **Chronic Tetanus.** Chronic tetanus may simulate irritative lesions of nerves or reflex contracture. Tetanus may be distinguished by the painful nature of the spasms, and because they always have periods of relaxation.

There is usually some relation between the onset of the spasms and external stimuli, such for example as manipulation or sudden variations in the external temperature which may start a spasm.

Tonic spasm of the muscles of the jaw would suggest the correct diagnosis to be applied to tonic spasms in other regions of the body. If a few months have elapsed since the reception of the injury the contracture is unlikely to be due to tetanus.

VII. PROGNOSIS

A purely hysterical disability is likely to be rapidly cured by suggestion, for which in many cases re-education is an effective substitute. A pure muscle-habit is often readily cured by re-education alone, although in individual cases, perhaps, suggestion might be more effective. Where the cause of the habit persists it should be removed if at all possible, as for instance, a painful scar on the sole. Reflex disabilities are, on the whole, much more difficult to deal with. There is little doubt that a reflex disability may persist as a muscle-habit, in which case it may be easily cured. Where, however, the reflex cause is still present and acting, it should be removed, otherwise the disability will be prolonged, especially if there is much vasomotor disturbance and the other features are present which mark the 'physiopathic' type of Babinski.

It is not possible to lay down rules for prognosis. The duration

of the disability is of some importance, since the longer it has remained untreated or has persisted under treatment the more difficult does recovery tend to be. It is true that a cure is often rapidly effected even after years, yet there can be no doubt that as the weeks and months go by, everything tends to make it less easy. Mere disuse, even when it has led to no organic complication, makes it increasingly difficult to restore the function. Anæsthesia, whether organic or functional, is unfavourable, although the anæsthesia of disuse may be rapidly overcome. Persistent pain is a serious drawback. The intelligence is always an important factor, since it is difficult to educate a stupid man in anything. It need scarcely be said that in every case the man's confidence must be gained, for unless he is satisfied that he is not suspected of malingering, all treatment is likely to be useless. Prognosis is often impossible until time shows whether the man has actually begun to improve.

VIII. TREATMENT

In the 2nd Northern General Hospital it is rare to see an uncomplicated hysterical case. The treatment of all purely functional and reflex cases is as follows:

1. Men suffering from purely functional disabilities are not grouped together, but are scattered throughout the hospital in the surgical wards, each man attending the re-education department as an out-patient. In the surgical wards the tone is generally good. The men are cheerful. Their very wounds are proof that they have been in the fray. In such wards there is always much good-natured chaff, and a special share falls to the functional cases, particularly when they are progressing under treatment. This chaff is undoubtedly one of the best of tonics. Moreover, there is in most cases also an organic disability requiring surgical supervision. Close co-operation between surgeon and re-educator is essential.

2. No patient is ever treated as a hysteric or a malingerer. Each man from the moment he enters the department is made to feel that his disability is very real. Men suffering from purely functional disabilities are extremely touchy. The malingerer, of course, is suspicious and surly, frequently so over-doing the part as to give himself away. But malingerers are few and far between, and many a man fires up and takes offence at a trifle simply because he is disgusted with himself for being disabled without having anything to show for it. For this reason functional cases are not too strictly disciplined by the re-educating staff. One man with a grievance may spoil much careful work. When it is

suspected that a man is really malingering—and such cases are rare—he is sent back to his surgeon.

3. Each man is examined and treated as far as possible in private until he has become accustomed to his surroundings and has lost some of his self-consciousness. Functional cases require careful handling throughout. They are always liable to take offence at some harmless therapeutic pleasantry or innocent word of encouragement.

4. The patient is from the first assured that while his disability is very real, there is no reason why it should not yield to treatment. If any part of the disability is due to actual and permanent damage to the tissues, he is warned not to look for any improvement in this direction. If an organic lesion is causing no trouble except through suggestion, an effort is made to convince him that this is not in any way disabling him. Where there is no organic lesion or one which is causing no trouble whatever, it is explained that through shock or otherwise he has lost control of his muscles, which are now doing exactly as they please, and require to be disciplined if he is to regain control. It is of vital importance that he should be trained to observe what muscles are at fault and wherein their fault lies, so that when the treatment is being carried out he may know what he is to try to do, and above all when he has succeeded in doing it. In a favourable case it is a great encouragement to him to watch the individual muscles gradually improving. If it is a case of incoordination he is taught first to relax all the muscles of the part and then to execute the particular movement in the simplest and most natural way. When the lost movement is very complex it may be necessary to build it up out of its component parts. When a muscle is in spasm it must be made to relax by removing all tension or else by stretching it. A flaccid muscle may be induced to contract by gentle tapping, or by electricity, or better still by excitation. Electricity (which is, however, seldom used, because it masks the muscular sensations) is employed in the form of the faradic current, with two terminals or in a bath. In the bath all the muscles of the part are simultaneously stimulated by the same current, so that the strongest group of muscles will prevail. **Simultaneous faradism** may be applied independently to each of the great nerve trunks of the part. By regulating the strength of current for each nerve it is possible either to balance the muscles against each other or to cause each group in turn to prevail over its antagonists. In this way the muscles work under varying tension, and their sensory nerves convey to the spinal cord and higher centres impulses which tend to recall to the patient the sensations which accompanied the vigorous use of his limb before it was disabled. **Excitation** consists of smart passive movements accompanied by simultaneous efforts at the corresponding movements on the part of the patient himself. If a muscle be suddenly stretched it will

contract in order to save itself from injury. If, on the other hand, it be suddenly relaxed, this can only be done by stretching its antagonists, and it will then contract reflexly in order to steady the joint. If these passive movements and involuntary muscular contractions are made to coincide with active effort on the part of the patient, each group of muscles will be trained to contract or relax at the very moment when its antagonists are relaxing or contracting. When the muscles are too feeble to stand such vigorous treatment it will be enough to raise the part against gravity and then to allow gravity to draw it down so that the increasing tension may induce the muscles to contract. Painful excitation is often valuable ; thus for the thigh smart slapping or kneading sometimes does well, and in the foot vigorous hyper-extension of the toes or 'crushing' them against each other by pressure on both sides of the foot will often produce rapid improvement even in a perfectly flaccid limb, provided there is no anæsthesia. Painful excitation may thus be used as a rough and ready test since response of the muscles shows that the reflex arc is in working order. Hyper-extension of the fingers is occasionally useful in wrist-drop. When the hand cannot be properly closed because of inco-ordination of the muscles, excitation in the form of successive flexion of the first, second, and third phalanges is of great value. It is difficult to treat overaction of the calf muscles causing tightening of the tendo Achillis because the foot offers such poor leverage. To overcome this take (i) a gutter splint about 9 inches long, wide enough to accommodate the thigh, and provided on each side about the middle with a hole so that the chain can be fastened to the splint, (ii) a good steel dog-chain, 36 inches long, and fitted at each end with a revolving swivel, (iii) a piece of white-pine board, 27 inches long, 3¾ inches broad, and about half an inch thick, with (*a*) one end narrowed to form a handle, (*b*) the other end fitted on its upper surface with two transverse strips of wood to form a groove for the chain, and (*c*) both sides of its broad part lipped downwards with thin wood so as to confine the foot (Fig. 146). Now let the patient lie on a couch on his face with the knee well flexed. Lay the gutter splint on the couch beneath the thigh. Fasten one end of the chain to one side of the gutter splint and, passing the other end through the hole on the other side, fasten it to the chain itself at such a height that the middle of the main part of the chain reaches just above the heel. Lift the board by the handle with the transverse groove upwards and laying it on the sole with one lip on each side of the foot slip the middle of the chain into the transverse groove, which should lie just behind the heel. On lowering the handle it will be found that the pressure can be limited to the metatarso-phalangeal region and that far more force is at one's disposal than can justifiably be employed. By alternately raising and lowering the handle while the

patient attempts the corresponding voluntary movements, excitation can be easily and efficiently performed. By means of a second groove nearer the handle of the board and a second chain attached to the lower end of the gutter splint the limb can be fixed and the tendo Achillis kept

FIG. 146.—Foot-lever for training over-acting calf muscles to relax.

on the stretch for any length of time, springs being fitted on if desired. Besides excitation, **special exercises** are often needed for individual cases, for an almost trivial change in the re-education may make all the difference in the result. Thus a slight readjustment of the muscular effort may double the stride. **Gymnastic exercises** and **drill** have their place, but in every case the man should be trained to recover his function in the simplest and easiest way. Thus in uptilting of the pelvis due to flaccidity

of the abductors of the hip, he should be taught to walk ; but if the body be vertical the muscles of the lower limbs will be hampered by having to support the body weight. He should therefore be put through walking movements on his back, in which case the limbs will have much greater freedom of movement. Further, the complex movement of walking should be built up by stages from its simplest components, namely elevation of the hips, adduction and abduction of the hips, flexion of the hips, knees, and ankles, and so on. Massage is of value where muscles have become atrophied through disuse, as in a flaccid limb, or worn out through over-action as in a long-continued clonus ; but great care must be exercised in choosing appropriate cases, since, like electricity, it is often of no value, and in spastic cases is actually harmful. **The curative workshops** may be useful in the later stages. In physiopathic cases the hot paraffin bath is valuable, and desiccated thyroid (parathyroid ?) gland has been given in a number of cases with results which appeared to justify further trial. Hypnotism is never employed.

Suggestion, of course, plays its part in the treatment of these cases as it does in every department of human and animal life. It is curious how often suggestion is regarded as a mysterious influence which leads a man to commit any kind of nonsensity. Suggestion is the most powerful and pervading force in life. It is responsible for all that is best as well as worst in national no less than in individual character. It initiates every habit and it is the basis of all education. Response to suggestion is therefore no evidence of hysteria and it is unscientific to apply the term ‘ hysterical ’ to conditions in the production and continuance of which suggestion has played no greater part than it does in the habits of everyday life, and in the treatment of which suggestion is itself of little value unless it takes the form of education and is accompanied by passive movements and the stimulation of the muscular sense by reflex contraction in addition to voluntary effort on the part of the patient. Any one who attributes to suggestion alone the production, continuance, and cure of these cases is himself a victim of suggestion.

TREATMENT OF PHYSIOPATHIC CASES

The treatment of these cases is often unsatisfactory unless a definite cause be found and removed.

A painful scar or sensory nerve irritation should be cured surgically before a course of re-education exercises is started. Appropriate splinting which allows of a degree of joint movement may be necessary at first. Use of the limb should be encouraged by the institution of carefully supervised

work of an interesting kind and exercises which are planned on the lines of a game. Small classes of similar types of case create a spirit of healthy competition amongst the men who compose the class, and this tends to accelerate progress as well as allowing greater numbers to be treated by a gymnasium staff. This type of treatment is much better attended and appreciated by the patients than the dull ' bend and stretch ' exercises recently employed. Diathermy will help to dissipate the vasomotor symptoms in selected cases.

If electrical stimulation be used at all, it should be employed only to a very limited extent as an aid to re-education. Routine faradization may suggest to the patient that a serious organic nerve lesion is the cause of his disability, and so influence his volition that he relies more upon artificial aids to correct his deformity than upon his own efforts.

The treatment should be as simple as possible, and if all apparatus and splints can be dispensed with, so much the better.

The local application of warmth usually does good, especially if it be explained to the patient that this treatment will become unnecessary as soon as vigorous muscular movements are restored. A bath of hot paraffin wax at a temperature of 130° F. is very useful. The thin layer of wax which sets on the skin when the limb is first plunged into the bath prevents the high temperature being felt as anything but a comfortable warmth by the patient. At the end of the bath the wax is peeled off the limb, which will now keep warm for quite four hours. The tendency of these cases, so treated, is towards recovery. Treatment by suggestion alone, without these aids, does not seem materially to hasten matters. Re-education should be started early in most of these cases, even though the treatment may not give quick results.

There is no doubt that where the vasomotor disturbance is considerable, the progress is not so good. On the other hand, where there is very little vasomotor disturbance, these cases tend to merge into the purely functional type, and are often rapidly cured by suggestion and re-education.

In these days the best result of treatment for all the above disabilities, whether purely functional or reflex, is of course fitness for military service in one form or other. In a few cases the man will be fit for the fighting line, in most it will be enough if he is fit for a labour battalion or for substitution. Even when it may be advisable to discharge him from the Army, it is something to have made him a more useful citizen.

VOLUNTARY MUSCULAR MOVEMENTS IN CASES OF NERVE LESIONS

(TRICK MOVEMENTS)

BY

PROFESSOR FREDERIC WOOD JONES, D.Sc.

VOLUNTARY MUSCULAR MOVEMENTS IN CASES OF NERVE LESIONS (TRICK MOVEMENTS)

When, after the experience of a few months of war, peripheral nerve lesions came to be treated upon what may be termed a wholesale scale, it was felt by many clinicians that their experiences were fast outrunning the amount of exact anatomical information obtainable in most of our text-books. In no connexion was this state of affairs made more manifest than in dealing with those cases which demanded a precise knowledge of the action of living muscles in the human body. Our anatomical text-books gave the actions of the muscles, they also gave the innervation of these muscles, and the lines along which information for the clinicians was to be had, consisted in arguing that since a particular nerve has been divided certain muscles will be paralysed, and therefore the actions carried out by these muscles will not be performed. The first stumbling-block—the lack of precise knowledge as to the arrangement of the motor fibres in mixed nerves, and the exact site of origin of branches to individual muscles—was soon largely rectified, but the question as to what action any living muscle can actually perform is, as it always has been, a difficult one to settle. Now, it has been within the experience of every one who has come in contact with a large series of cases of nerve lesions that, at times, after the undoubted division of a motor nerve, the resultant paralysis has not been so great as would have been expected from a study of text-book anatomy. If it is taught in the text-books that a certain joint is bent by the action of a definite muscle, and this muscle is supplied by a definite nerve, then, when this nerve is divided, the expectation will be that since the muscle is paralysed, the action of bending the joint will not be performed. Not by any means uncommonly, this expectation is not fulfilled, for the patient continues to possess the power of bending the joint. Two explanations are at once forthcoming to account for this anomalous state of affairs. It is possible that, in this particular case, the nerve supply of the muscle is not that which is usually given in the text-books—that some other nerve sends branches to the muscle, and it is not paralysed at all. Or, it is possible that it is paralysed, and that some other muscle, or combination of muscles, may perform the action usually regarded as the exclusive function of this one. The first alternative has had its advocates, but we, as anatomists, need have little fear that a large revision of the text-book teaching upon the nerve supply of muscles will be necessary as an outcome of the

study of war injuries. As a matter of fact, routine electrical testing upon the structures as they are exposed on the operating table should form a part of all operative work, and when this is carried out the instances in which an appeal has to be made to abnormality of nerve supply are reduced to a minimum. In all cases cited in this paper this procedure has been adopted. With regard to the second alternative there is still a great deal of confusion. Much erroneous teaching has been put forward during the war, and many false conclusions arrived at in consequence of the deceptive nature of some of the voluntary movements possible after complete section of motor nerves. Testing voluntary movements is a business to be undertaken with a judicial mind, and at the best it is a difficult affair. It is easy to determine that a joint bends : it is by no means easy to determine beyond doubt what agent caused its bending.

It must never be forgotten that in testing voluntary movements we ask the patient to perform some action ; we do not ask him to use certain muscles. The cortex of the patient neither knows of nor cares for muscles, and his volition will therefore be effected by any agent capable—even in the lamest and most halting way—in responding to the volition. In some cases no agent having the power to perform the desired movement will be at hand, but at times some muscle may achieve a flicker in the right direction, or at times a perfect substitute for the paralysed muscle is prepared to take on the work. In any case, whatever beginning can be made in the production of the lost movement, it is probable that it will be steadily cultivated by the patient. The effort to respond to a cortical volition by *any* agent is very remarkable, the most unlikely muscles will contract in an endeavour to effect the desired movement : no man can flex his wrist with his platysma, but if the medical officer and the patient are both determined on doing their best many men will attempt it. Among the muscles which will be called on in the attempt to perform a lost movement are the antagonists of the desired movement, or any or every member of the groups of muscles having a general antagonism to the movement of volition. If, as a substitute for the paralysed flexors of a joint, the extensors of that joint be cortically activated, the volition of flexing will naturally not be attained ; but if the extensors of some neighbouring joint be contracted it is possible that a relative and passive flexion of the paralysed joint will result, and thus the volition may be achieved. Once the patient has learned this trick the chances are that he will cultivate it, and the working of his perfected effort may be extremely difficult to detect. In the limits of the present paper I have included ' trick ' movements, because although they do not throw much light upon normal muscular movements they have led some observers to false assertions as to the incorrectness of orthodox text-book teaching.

In all the cases which are recorded here, and from which conclusions are drawn, the author has personally seen the condition of the nerve as exposed at the operation, and has checked the finding by the electrical tests. If a nerve is reported as divided, the statement means that the author has seen the complete severance in the continuity of the nerve, and witnessed the failure of the exposed nerve to react to faradic stimulation. When movement is spoken of as being produced by the action of muscles, it must be understood that a real active movement of the part is achieved. In no case has a mere questionable flicker been reported

FIG. 147.—Complete division of musculo-cutaneous nerve.
Flexion of forearm by supinator longus.

as a voluntary movement. In all cases illustrated the patient has been so arranged that the active movement has been carried out against the action of gravity.

A. COMPLETE DIVISION OF THE MUSCULO-CUTANEOUS NERVE

Paralysis of biceps and brachialis anticus. This is not at all a common lesion, and in only one of the cases that I have seen was the nerve actually severed by the passage of a projectile. In only one case of complete division (Pte. G. H., 8th R. Sussex, 2288), with the musculo-spiral intact, was there any evidence that the brachialis anticus retained any power of contraction. In this case the contraction was palpable but localized,

and even in the most advantageous position it failed to produce any flexion of the elbow. In every case of paralysis of the biceps and brachialis anticus in which the musculo-spiral nerve was intact, the elbow was capable of immediate and strong flexion produced by the supinator longus (see Fig. 147). Despite recent teaching the supinator longus is always a flexor of the elbow-joint. The flexion of the elbow produced by the supinator longus is a powerful and precise action, and it is carried

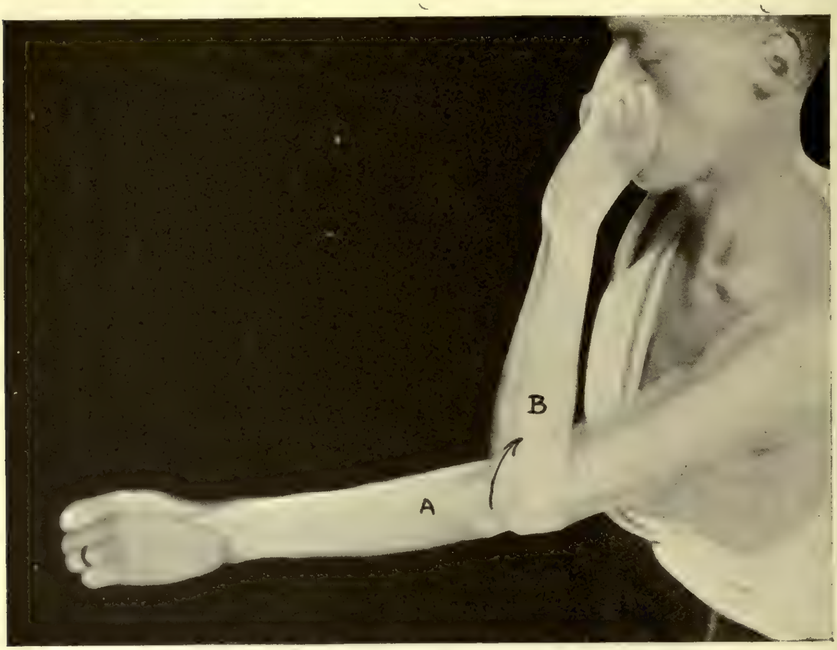


FIG. 148.—Complete division of musculo-cutaneous and musculo-spiral nerves. *Flexion of forearm by pronator radii teres.*

out with the hand in a useful working position. It is indeed often a matter of great difficulty to re-educate the patient in the use of the brachialis anticus and biceps, even after these muscles have perfectly recovered their voluntary contractibility.

B. COMPLETE DIVISION OF THE MUSCULO-CUTANEOUS AND THE MUSCULO-SPIRAL NERVES

Flexion of the elbow is performed by the pronator radii teres (see Fig. 148). This flexion is nothing like so powerful, nor so complete, as that produced by the supinator longus. The action requires some cultivation by the patient, and even after some considerable interval the flexion may not be sufficiently complete to raise the hand to the mouth. In the case illustrated the pronator radii teres was the only muscle which was used

to perform the action, and the flexion produced was a forcible and useful movement when the forearm was maintained fully pronated.

The Action of the Biceps upon the Elbow-joint. Since there has recently been some attempt at revision of the established teaching concerning the action of the biceps as a flexor of the elbow-joint it is worth recording that apart altogether from the phylogenetic history of this flexor, and its undoubted action as a flexor in the normal living human subject, its action is well seen in a very wide series of war injuries. Contracture of the elbow-joint following a flesh wound limited to the biceps muscle is a common enough condition, and is comparable with the flexion of the knee so commonly seen following flesh wounds of the hamstrings. Cases of spasm of the biceps may follow prolonged splintage or slinging, and may be maintained with a hysterical basis for a period extending over years. (*Case*, Pens. G. C., 6th Glocs., 267306, shrapnel flesh wound middle r. biceps—elbow flexed to right angle from July 19, 1916 to May 19, 1919. No other muscle or nerve involved.) Discrete contracture of the biceps fascia, without the involvement of any other structure, also produces flexion of the elbow.

C. COMPLETE DIVISION OF THE MUSCULO-SPIRAL NERVE

(1) *Paralysis of the extensors of the wrist.* Although 'drop-wrist' is such a classical symptom of musculo-spiral paralysis, and although it is so strikingly complete in all cases of hysterical palsy, it not infrequently happens that a most astonishing power to extend the wrist against gravity persists in cases of complete division of the musculo-spiral nerve above the supply of all the extensor muscles. The production of this extension is a true 'trick' movement, for it is done by pulling on the tendons of the extensor communis digitorum by flexing the metacarpo-phalangeal joints with the interossei. As the metacarpo-phalangeal joints are flexed, the digital extensors are tightened, with the result that the hand is forcibly extended at the wrist-joint (see Fig. 149). It will be readily understood that in all cases of trick movements the detection of the trick is far more difficult than would be supposed from an inspection of a photograph of the action, the patient often possessing a subtle power to manipulate one joint while the observer's attention is directed to a neighbouring one.

(2) Although in a complete musculo-spiral lesion the metacarpo-phalangeal joints cannot be extended it must not be forgotten that the two terminal phalanges may be straightened from the flexed position by the action of the interossei. This action is, at times, mistaken for musculo-spiral activity, and it is especially liable to cause confusion if the hand be examined whilst supported on a splint.

(3) The movements of the thumb in cases of division of the musculo-

spiral nerve have proved deceptive in a very large number of cases. It is by no means uncommon for the patient to possess the power of extension in the terminal joint, or at times to show ability to extend the thumb at the metacarpo-phalangeal joint. In by far the greater number of these cases the action is produced as a trick movement, the terminal joint being first bent by the flexor pollicis longus and then, when flexion is released,

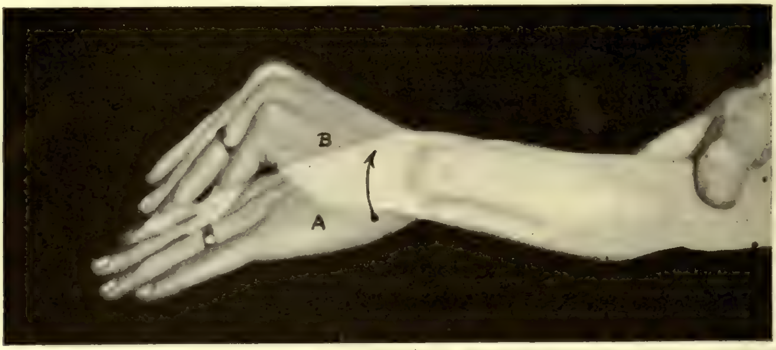


FIG. 149.—Complete division of musculo-spiral nerve.
Extension of wrist by flexion of fingers.

FIG. 150.—Complete musculo-spiral paralysis.
Extension of terminal phalanx of thumb.

extension is produced by the passive pull of the long extensor. But in other cases the movement is more complex. It will be noticed that when the thenar muscles act upon the thumb, extension of the terminal phalanx is normally produced. This extension may be brought about by the passive pull of the extensor pollicis longus against the ulnar abductors of the thumb in the normal action. Or it may be done by a direct pull upon the sesamoid, and so upon the head of the metacarpal bone and front of the metacarpo-phalangeal joint. This pull tends to bring the

metacarpal forward, and so create a relative extension of the last two joints.

In the patient illustrated at Fig. 150 this was probably the case, since upon the left side this patient had a complete division of the ulnar as well as the musculo-spiral and was quite incapable of producing a movement in his left thumb like that illustrated in his right. At times it is possible that the abductor brevis may produce an active pull upon the expansion to the long extensor tendon ; but I do not think these cases are at all common. All movements of extension produced by the thenar muscles may usually be detected by the wriggling motion imparted to the metacarpo-phalangeal joint of the thumb ; but it is not true, as is so commonly taught, that extension of the terminal joint cannot be produced, in cases of musculo-spiral paralysis, when the thumb is abducted, unless the precaution be taken that this abduction and immobilization affects both the metacarpal and the first phalanx.

D. COMPLETE DIVISION OF THE ULNAR NERVE

(1) Paralysis of the flexor carpi ulnaris is particularly difficult to test. It is more easy to appreciate the voluntary action of this muscle in producing the movement of ulnar deviation of the hand, than by attempting to estimate its condition during active flexion of the wrist. There are probably few muscles in the body in which the apparently simple task of estimating voluntary action by observation and palpation is so exceedingly difficult.

(2) The action of the interossei in producing adduction and abduction of the digits may be simulated by other muscles, and great caution is needed before statements are made as to recovery in ulnar nerve lesions on the strength of the patient showing some ability to spread the fingers apart and close them together again. It is a commonplace that as we open our hands with the extensors our fingers tend to spread apart, and as we close our fist with the flexors, our fingers are adducted. The movement of abduction effected by the extensors may be perfected in a very remarkable manner, and it is not uncommonly mistaken for interosseus action (see Fig. 151). It is to be noted that in true interosseus abduction the fingers are all spread from the middle finger as a centre, but in extensor abduction this does not hold good, for the fingers are spread as a fan is opened and, in the case photographed, the fourth digit remains more nearly at rest than the third. The only satisfactory method of performing the test for interosseus action is to isolate each finger, and test its power of adduction and abduction to and from the middle line without permitting the long flexors or extensors to come into play. There are two additional points to be noted concerning the abducting power of the extensors.

(3) The extensor minimi digiti proprius is an exceedingly powerful

abductor of the little finger. Its action may easily be mistaken for that of the abductor minimi digiti ; and the fact that the little finger possesses this added mechanism of abduction accounts for the permanently abducted position which the finger takes up even long after the recovery of a sutured ulnar nerve (see Fig. 152).

FIG. 151.—Complete division of ulnar nerve-paralysis of interossei.
Abduction and adduction of fingers by flexors and extensors.

FIG. 152.—Recovery from ulnar paralysis.
Abducted position often assumed by little finger.

(4) Although the extensor communis tendon to the index finger is able to produce abduction of the index in the general movement of extensor abduction, the extensor indicis proprius acts as a well-marked adductor. In the absence of any interosseus power, therefore, the index finger may be both adducted and abducted to and from the middle line (see Fig. 153).

(5) The action of the long extensors upon the two terminal phalanges may prove a source of erroneous diagnosis. It has often been said that

the action of the long extensors upon these two joints is but a feeble one; and recently it has been asserted very emphatically that not only have they no action whatever, but by the anatomical arrangement of their tendons it is impossible that they should have any action. It is quite certain that the anatomical condition of the long extensor tendons, as properly displayed by dissection, is such as to permit extension of the two terminal joints of the fingers. It is equally certain that when the ulnar nerve is completely divided and the action of the interossei is entirely absent the two terminal joints of the fingers can be extended by the action of the long extensors acting alone. This is not an abnormal

FIG. 153.—Complete division of the ulnar nerve. Pte. W. R., gun-shot wound, left elbow, April 17, 1918. Nerve found completely divided, December 11, 1918. Test, May 9, 1919, no faradic or voluntary response in any ulnar muscle. Photo, May 1919.

Adduction of the index finger produced by the extensor indicis proprius. Abduction by extensor communis digitorum.

action; it is one that can be witnessed in any case of division of the ulnar nerve, though the extension produced may not be so complete in all cases as in that illustrated at Fig. 154.

(6) The statement that in complete ulnar lesions the metacarpo-phalangeal joints of the little and ring fingers cannot be flexed is, as a rule, incorrect. Although in the characteristic position of ulnar paralysis this joint in the little finger is extended, and the flexor digitorum sublimis has already produced a flexion of the first interphalangeal joint, nevertheless a considerable degree of bending may be produced in the metacarpo-

phalangeal joint by further action of the tendon of the flexor sublimis. In the ring finger flexion of the metacarpo-phalangeal joint is readily produced by the flexor sublimis in cases of complete ulnar paralysis.

E. COMPLETE DIVISION OF THE MEDIAN NERVE

(1) Several incorrect teachings concerning the failure to produce flexion in certain finger-joints are current at the present time. The amount of paralysis that follows complete section of the median nerve is far less than would be imagined as the result of a study of anatomical

FIG. 154.—Complete division of the ulnar nerve. Pens. C. H. H., gun-shot wound, right elbow, October 21, 1917. Nerve found completely divided, April 26, 1919. Test, April 26, 1919, no faradic or voluntary response in any ulnar muscle. Photo, May 1919.

Extension of the two terminal phalanges by the extensor communis digitorum.

text-books, and it is far less than that asserted by some observers of nerve injuries during the war.

(2) It is said that in cases of complete median interruption the patient is unable to flex the second phalanges of any of the fingers. Flexion of the second phalanges, however, can readily be brought about by the flexor profundus *after* this muscle has bent the terminal joint. The second phalanges of minimus, annularis, and medius can always be bent in complete median paralysis by the action of the intact flexor profundus (see Fig. 155). The flexion produced is of a characteristic type, and may best be described as ' winding up the finger '.

(3) It is also asserted and emphasized by deductions from observations on the cadaver that the interossei cannot produce flexion of the metacarpo-phalangeal joints ; these joints being bent by the action of the lumbricales

only. This teaching is absolutely wrong, and it has led to the very incorrect diagnostic criterion that in median nerve paralysis the metacarpo-phalangeal joints of index and medius cannot be flexed. Every patient with complete division of the median nerve has power to flex the metacarpo-phalangeal joints of these fingers, and the flexion in these cases is produced, as it is in the normal subject, by the action of the interossei, although, of course, the lumbricales assist in the action (see Fig. 156).

(4) The common statement that the distal phalanges of index and medius cannot be flexed needs very careful qualification. If the index

FIG. 155.—Complete division of the median. Pte. C. W., gun-shot wound, left arm, April 10, 1918. Median found divided, July 17, 1918. No voluntary or faradic response in median muscles, April 26, 1919. *Flexion of index and medius at the metacarpo-phalangeal joints.*

finger be grasped, and the patient is told to bend the top joint of that finger only, no action of flexion is produced. If the same test be applied to medius a definite flexion movement can usually be evoked. But if the patient is merely asked to bend the fingers, or especially if he is asked to make a fist, then some flexion of all joints of all the fingers is produced. In some cases a very fair fist may be made in cases in which the median nerve is completely divided (see Fig. 155). Evidently, if the volition is a general one, the main action of the flexor digitorum profundus brought about by the route of the ulnar nerve is sufficient to produce a flexion of all the fingers. But if the volition is merely limited to the exclusive median portion destined for the index finger, then no contraction of the muscle takes place.

(5) Flexion of the terminal joint of the thumb is sometimes possible in median nerve lesions in which the long flexor is paralysed. The flexion, though definite, is not complete, and is stamped by that characteristic

inability to operate in the presence of any resistance which usually accompanies movements produced by relaxation of opponents.

(6) Flexion of the metacarpo-phalangeal joint of the thumb has been said to be impossible without the action of the muscles innervated by the median nerve ; but the ulnar muscles inserted to the ulnar sesamoids are capable of producing this movement, and in this instance, as in the next two to be examined, we have an example of the almost utter impossibility of diagnosing lesions of the nerves supplying short muscles of the thumb merely by looking at the movements of which the thumb

FIG. 156.—Complete division of the median. Pte. A. H., gun-shot wound, right arm, March 31, 1918. Nerve found divided, September 21, 1918. No voluntary or faradic response in median muscles, May 12, 1919.

Ability to make a fist with the median divided above the supply of the long flexors of the digits.

is capable. Electrical tests and careful palpation of the thenar muscular mass are essential preludes to a diagnosis.

(7) It is best to state quite dogmatically at the outset that the complex combination of muscular movements which give effect to the volition of opposing the thumb to the other digits, is often perfectly carried out in cases of complete division of the median nerve (see Fig. 157). In performing this action some muscle is needed to pull the metacarpal bone of the thumb in a palmar direction, another muscle is required to move the thumb towards the ulnar side of the palm, and to complete the process of perfect opposition some muscle is required to produce a rotation of the thumb. The extensor ossis metacarpi pollicis produces a forward movement of the metacarpal bone, and in the production of opposition

in cases of median paralysis the part played by this muscle is generally apparent. When the thumb is pulled in a palmar direction the adductor pollicis will produce the ulnar sweep, and, with effective opposition from the extensor ossis, will also produce a deceptive degree of rotation of the thumb. In many cases in which the movement of opposition is quite perfect, that part of the adductor obliquus muscle which is inserted to the radial sesamoid effects a rotation not to be distinguished from true opponens opposition as in the case illustrated in Fig. 157. Digital examination of the metacarpal of the thumb will reveal the atrophy of

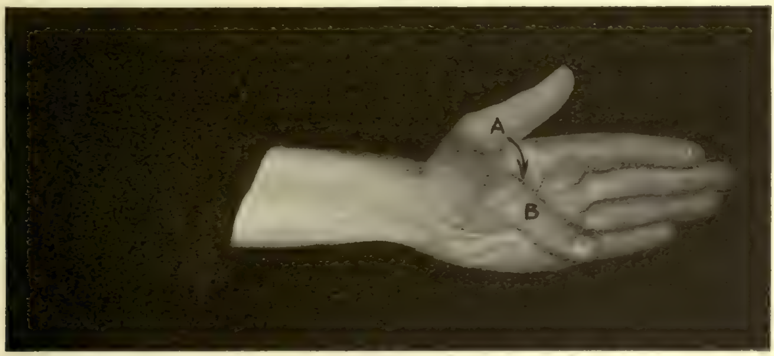


FIG. 157.—Complete division of the median. Pte. C. W., gun-shot wound, left arm, April 10, 1918. Nerve found divided, July 17, 1918. April 26, 1919, no faradic or voluntary response in any median intrinsic muscle.

Opposition of the thumb in complete median paralysis.

the opponens in these cases, but mere inspection of the movements produced may not be taken by any anatomist or any clinician as evidence of median recovery.

(8) The loss of the abductor pollicis in median paralysis is often extremely well compensated by the power of the extensor ossis metacarpi pollicis to pull the whole thumb in a palmar direction. A good deal of reliance has been placed on the ‘ abduction test ’ in cases of median paralysis ; but in a certain number of cases this spurious abduction brought about by a muscle innervated by the musculo-spiral nerve is a very well-defined and forcible action, though naturally its range of movement is never so great as in that produced by the abductor brevis (see Fig. 158).

F. COMPLETE PARALYSIS OF BOTH MEDIAN AND ULNAR NERVES

(1) It is in this condition that the typical ‘ ape hand ’ is developed. The essential feature of this hand is the flatness of the palm, and the rotation of the thumb in a direction opposite to that produced by the

opponens. The thumb ranges itself alongside the index finger with its palmar surface directed in a palmar direction, in the same manner as the remainder of the digits. It is rather curious that the production of this position of the thumb is ascribed by Benisty[1] to the action of the adductor pollicis—a muscle which is of necessity paralysed in these cases.

The muscle which produces this movement (which may be termed pronation) in the thumb is the extensor pollicis longus, which is thus, as regards rotation of the thumb, the opponent of the opponens.

(2) One very curious and deceptive action seen in some cases is that illustrated in Fig. 159. Although all the finger flexors are completely paralysed, distinct and forcible flexion, which enables the patient to

FIG. 158.—Complete division of the median. Nerve divided for pain, February 20, 1919. No recovery, May 26, 1919.

'Abduction' movement of the thumb produced by extensor ossis metacarpi pollicis.

scratch with the finger-nails, and to close the hand, is readily carried out. This trick action is exactly the opposite to that mentioned in those cases of musculo-spiral paralysis in which the wrist may be raised by bending the fingers; for here the bending of the fingers is effected by raising the wrist.

(3) An action which has led to more confusion in diagnosis than probably any other is that power of wrist-bending which is normal to the extensor ossis metacarpi pollicis. The movement of the wrist produced by this muscle is illustrated in Fig. 160, and in this case the action effected against gravity is a forcible one, although under these conditions its range is not very great.

[1] *Clinical Forms of Nerve Lesions*, 1918, pp. 55 and 116.

FIG. 159.—Complete division of both ulnar and median. Pte. A. B., gun-shot wound, right arm, April 10, 1918. Both nerves found divided, June 11, 1918. No recovery, May 26, 1919.

Flexion of the fingers produced by extension of the wrist.

FIG. 160.—Complete division of ulnar and median. Pte. A. R., gun-shot wound, left axilla, July 19, 1918. Both nerves found divided, December 13, 1918. No faradic or voluntary response in any median or ulnar muscle, April 5, 1919.

Flexion of the wrist produced by the extensor ossis metacarpi pollicis.

G. NERVE LESIONS OF THE LOWER EXTREMITY

In the leg there are but few voluntary muscular actions which are likely to deceive, but it may be said at once that if voluntary power is examined for with the patient lying on his back with his heel resting on

the couch, almost any conclusion may be arrived at. The patient has only to push or to pull against his heel as a fixed point to produce movements of his foot in either direction ; and this push or pull may be effected by any muscle capable of taking a leverage from the couch.

(1) The action of the peronei as elevators (dorsi-flexors) or depressors (plantar-flexors) of the foot has been somewhat debated. In the first place the peronei belong to the external popliteal group of muscles and their normal action on the foot is to produce eversion. Eversion is itself a movement of greater possibilities in the position of dorsiflexion. But it has often been said that anatomically the peronei—or some of them—are muscles which produce plantar-flexion. There is no doubt that in the normal condition the peronei act with their group, and come into play during dorsiflexion of the foot. Suppose, however, the internal popliteal nerve is completely divided and the calf muscles are paralysed, will a movement of plantar-flexion be produced by the peronei ? In the great majority of patients there remains no power to depress the foot under these conditions, for the peronei, even if anatomically capable of producing plantar-flexion, cannot be dissociated in their action from the remaining muscles, supplied by the external popliteal, which produce dorsiflexion. But, at times, the patient possesses the power of contracting the peronii without contracting the other external popliteal muscles—he can dissociate the action of the peroneus group. In these cases plantar-flexion and eversion is the result ; and if the action be not carefully studied, it may be mistaken for evidence of internal popliteal recovery (see Fig. 161). One might, therefore, say that normally the peronei were muscles which do not act upon the ankle-joint, but which produce eversion of the foot when in a position of dorsiflexion. Occasionally, however, in cases of internal popliteal paralysis, these muscles may be dissociated by the patient from the remainder of their group and may then be used as plantar-flexors.

CONCLUSIONS

The purpose of this chapter is to emphasize the following fact. (1) That estimating the condition of injured nerves by the study of the voluntary movements of which the patient is capable, is an extremely difficult and, at the best, somewhat uncertain business. (2) That the re-education of muscles, in cases of nerve injury, is a matter requiring far more anatomical knowledge than is often brought to bear upon it ; since without proper care it will certainly result in the education of trick movements which, when perfected, are accepted as evidences of recovery. (3) That much of the teaching upon muscular action which has been put forward from a study of nerve lesions during the war is erroneous.

Anatomists therefore should exercise great caution before authorita-

tive sanction is given to teaching which may lead to false estimates of the damage done to nerves and the recovery of nerves after operation; since on the one hand operation may be negatived or delayed, and on the

FIG. 161.—Complete division of the internal popliteal; verified, May 30, 1919. *Action of the disassociated peroneii muscles.*

other operative procedures which are futile may be encouraged, or legitimate operation may be estimated as having an unreal success. In any case the result of such an error may be that the period which marks the transition from the sphere of activity as a serving soldier to that of useful civil employment may be very much prolonged. It is therefore necessary for surveyors and anatomists to be far more critical than they have hitherto been.

A STUDY OF THE RESULTS OF OPERATIONS FOR NERVE INJURY AT BANGOUR (EDINBURGH WAR HOSPITAL)

BY

MAUD F. FORRESTER-BROWN, M.D., B.S. Lond.

A STUDY OF THE RESULTS OF OPERATIONS FOR NERVE INJURY AT BANGOUR

The following tables represent the results in a consecutive series of cases which were operated on in the Edinburgh War Hospital from 1916 to 1919; only cases are included which had been discharged from the hospital by July 1919, and, with a few exceptions, only those which had been operated on at least six months previously. The statistics of the large series of nerve cases operated on since is not yet available. A few cases which would otherwise have been included have had to be omitted owing to the loss of their operation records.

The cases whose final nerve condition is recorded below were either examined personally by the writer, or in a few instances detailed reports of their condition were received from the other orthopædic centres, for which we have to thank the surgeons in charge. No reports of patients on themselves have been included, except with regard to the form of work which they are doing. A set of questions was sent out to the English cases, but the answers were too vague to be of scientific value.

As very few cases return to the absolute normal after a nerve injury, and as the relative improvement in the functions of a mixed nerve is very variable after operations, it was considered advisable to divide up the evidence of recovery under the headings Motor, Sensory, and Trophic, thus giving a juster picture of the degree of recovery attained.

Under these headings, the terms Complete, Incomplete, and Nil were used as the three simplest standards.

By *complete* was understood:

1. Return of voluntary power in all the *muscles* supplied by the nerve below the lesion, even if these remained weaker than normal at the time of examination, because it was believed that use alone was required at this stage to restore the full strength.

2. Return of *sensation* to wool, prick, deep pressure and the position of joints. The compass test, as recommended by Head, was not used, owing to lack of time, so that possibly some of our cases might have failed to respond to this more delicate test.

3. *Trophic* recovery was considered complete when there was no marked wasting of the muscles, nor appreciable skin or vasomotor changes.

Incomplete includes those with any evidence of recovery, from very slight degrees, to cases which nearly attained the standards detailed above. It would have been desirable to grade these cases more accurately,

but the transition from one degree to the next is so slight that their classification became too complicated.

Two very important factors had to be considered in assessing the results of any operation, i.e.,

1. The *period* which had elapsed *since* the *operation*, for it is obvious that in dealing with a slow process like nerve regeneration it is easy to find cases which after months show little apparent benefit from the operation, and which may yet in the course of time give a complete recovery.

2. The *lesion* for which the operation is performed. This is of especial weight in cases of neurolysis, for it is clear that a nerve, some of whose bundles have been destroyed, cannot be expected to show the same benefits when relieved from compression, as one whose axons are intact. In the case of nerve suture, the amount of destruction and consequent extent of operative interference required, is liable to affect the result, though, as will be seen below, to a lower degree than might have been expected.

In judging the functional result of any operative procedure (the patient's subsequent capacity for work), a third factor has to be considered, i.e.,

3. The presence of *complications* :

Fractures, ununited, mal-united, or resulting in synostosis.

Joints ankylosed, or painful.

Tendons adherent or destroyed.

These form often a more serious impediment to the man's return to ordinary work than the nerve injury for which the operation was done, and therefore their presence has been noted in the table which deals with working capacity. It has been our effort in this hospital never to overlook such complications when dealing with the nerve injury, but unfortunately they are often less amenable to treatment than the nerve condition.

The number of cases examined whose results are analysed in the following tables are :

85 sutures, of which 15 made complete recoveries.

79 neurolysis, of which 11 made complete recoveries, and only one failed to show some improvement.

The remaining cases, making a total of 456, sent written reports on themselves, and are only included in the study of working capacity and of recrudescent sepsis.

TABLE I

Nerve Sutures

Nerve Sutured.	*Total No.*	*Degree of Tension.*	*Time Observed after Operation.*	*No. of Cases showing Recovery.* *Motor.* *Complete.*	*Motor.* *Incomplete.*	*Sensory.* *Complete.*	*Sensory.* *Incomplete.*	*Trophic.* *Complete.*	*Trophic.* *Incomplete.*
Posterior cord of brachial plexus	2	Arm adducted (1 full range not obtained	1–2 yrs.	1	1	1	—	1	—
Median sutured 1 practically complete recovery 3 quite complete recoveries	15	¼ in. gap: 1 case (wrist and elbow at right angle)	8 mths.	—	0	—	1	—	0
		1 in. gap: 2 cases (forearm)	10 mths.	1	—	1	—	—	1
			21 mths.	0	—	0	—	—	0
		1¼ in. gap: 2 cases (forearm) 1 complete recovery	6 mths.	1	—	1	1	—	—
			19 mths.	0	—	0	—	0	—
		1½ in. gap: 3 cases (forearm)		2	—	1	2	1	2
		1¾ in. gap: 2 cases (arm and elbow) 2 complete recoveries	14 mths. 34 mths.	2	—	2	—	2	—
		2 in. gap: 2 cases (arm and forearm)	7 mths. 16 mths.	2	—	—	2	—	2
		Forearm shortened: 1 case complete recovery	12 mths.	1	—	1	—	1	—
		'Elbow flexed': 2 cases	7 mths.	0	—	0	—	0	—
			21 mths.	1	—	1	—	1	—
Ulnar sutured (without transposition) 1 practically complete recovery 1 quite complete recovery	11	¼ in. gap in arm: 1 case	25 mths.	0	—	1	0	—	0
		¾ in. gap in forearm: 2 cases	5 mths.	—	1	—	1	1	—
			19 mths.	—	1	—	1	1	—
		1¼ in. in forearm: 1 case	7 mths.	—	1	—	1	—	1
		3 in. in forearm: 1 case	26 mths.	0	—	—	1	0	—
		'Wrist flexed': 4 cases 1 complete recovery	7–10 mths.	2	2	1	3	3	1
		Unrecorded: 2 cases	11 mths.	—	1	1	—	—	1
			31 mths.	0	—	—	1	0	—

TABLE I (*continued*)

Nerve Sutured.	*Total No.*	*Degree of Tension.*	*Time Observed after Operation.*	*No. of Cases showing Recovery.* *Motor.* *Complete.*	*Motor.* *Incomplete.*	*Sensory.* *Complete.*	*Sensory.* *Incomplete.*	*Trophic.* *Complete.*	*Trophic.* *Incomplete.*
Ulnar transposed and sutured	17	½ in. gap at elbow: 1 case	27 mths.	—	1	—	1	—	1
(No absolutely complete		¾ in. gap: 2 cases	5 mths.	—	1	—	1	0	—
recoveries but several nearly so)			11 mths.	1	—	0	—	0	—
		1½ gap: 2 cases (forearm)	1–2 yrs.	—	2	—	2	—	2
6 developed neuromata out of 19 cases		1½ in. gap: 2 cases (elbow at 100°)	7–12 mths.	—	2	1	2	1	2
(1 recorded under median and ulnar sutures)		2 in. gap: 2 cases (elbow at 90°) 1 neuroma	1–2 yrs.	—	1	—	1	—	1
		2½ in. gap: 1 case (elbow at 45°)	1 yr.	1	—	0	—	1	—
		3 in. gap: 1 case (elbow and wrist flexed) 1 neuroma	3 yrs.	0	—	0	—	0	—
		3¼ in. gap: 1 case (elbow flexed)	11 mths.	—	1	—	1	0	—
		'Elbow at right angle': 3 cases 2 neuromata, done again	22 mths. 26 mths.	0	—	0	—	0	—
		'Elbow acutely flexed': 1 case	11 mths.	1	—	0	—	1	—
		Unrecorded: 1 case	1 yr.	—	1	—	1	—	1
Median and ulnar sutured	1	2 in. gap in median; 1 in. in ulnar: 1 case	14 mths.	—	1	0	—	0	—
Median sutured and ulnar transposed and sutured	4	½ in. in median; 1½ in. ulnar; neuroma on ulna, done again: 1 case	1 yr.	0 ulnar	median —	0 ulnar median	1 —	0 ulnar median	— —
		¾ in. median; 1 in. ulnar: 1 case	over 2 yrs.	—	both	both	—	both	—
		2¼ in. median: 1 case (elbow at 90°)	1–2 yrs.	—	both	—	both	—	both
		'Elbow flexed': 1 case	2–3 yrs.	—	both	—	both	—	both
Musculo-spiral sutured	15	½ in. gap; elbow acutely flamed; complete: 1 case	25 mths.	1	—	1	—	1	—
7 complete recoveries 3 without any recovery Others progressing well		¾ in. gap: 4 cases 2 cases	8–10 mths.: 2 cases	—	1	—	1	—	1

Musculo-spiral (*continued*)		2 complete recoveries	2 yrs.	2	—	2	—	2	—
		1 in. gap : 1 case elbow acutely flamed 1 complete recovery	18 mths.	1	—	1	—	1	—
		1½ in. gap : 3 cases 1 arm adducted 1 elbow at 80° 1 elbow at 90° 1 complete recovery	8–12 mths.	1	2	0	1	2	1
		Unrecorded : 5 cases 2 complete recoveries	20 mths. : 1 case	—	0	—	0	—	0
			23 mths. : 1 case	—	1	—	1	—	
			24–7 mths. : 3 cases	2	—	2	—	2	—
Musculo-spiral transposed and sutured 1 complete recovery	1	Gap not recorded : 1 case	17 mths.	1	—	1	0	1	—
Sciatic and its branches sutured Sciatic, 7 Both popliteals, 2 Internal popliteal, 3 External popliteal, 7 1 complete recovery (internal popliteal)	19	¾ in. gap at fibula : 1 case (knee flexed to 30°)	9 mths.	1	—	—	1	—	1
		1 in. gap : 2 cases (at 90°, 1 ; at 135°, 1)	21 & 22 mths.	—	2	—	2	—	1
		1½ in. gap : 4 cases (knee 90°–100°)	6–12 mths.	—	4	1	—	—	2
		2 in. gap : 1 case (knee at 90°)	9 mths.	—	1	0	—	—	1
		2½ in. gap : 3 cases (knee 45°–90°)	8 mths. : 1 case	—	1	0	1	—	0
			15–17 mths. : 2 cases	—	2	—	1	—	1
		2¾ in. gap : 2 cases (knee 90°)	2½ mths. 7 mths.	1	1	1	—	—	1
		3 in. gap in buttock : 1 case (knee at 90°)	28 mths.	0	—	—	1	0	—
		Knee at 80° : 1 case (sciatic) 1 unrecovered	15 mths.	0	—	0	—	0	—
		Unrecorded : 2 cases	6 wks.	0	—	0	—	0	—
		1 unrecovered, external popliteal tendon slinging down	22 wks.	—	1	—	1	—	1

TABLE II

NEUROLYSIS

Nerve Freed.	Total No.	Condition of Nerve.	Time Observed after Operation.	Motor. Complete.	Motor. Incomplete.	Sensory. Complete.	Sensory. Incomplete.	Trophic. Complete.	Trophic. Incomplete
Median freed	31	Extensive scar surrounding nerve and adhesions to muscles: 16 cases	under 1 yr.: 5 cases	1	4	0	3	—	3
			over 1 yr.: 7 cases	7	—	3	4	5	2
		3 complete recoveries	2 yrs. and over: 3 cases	2	1	—	1	2	1
		Scar invading nerve: 3 cases	7 mths. (twice done)	1	—	—	1	—	1
			16 mths.	1	—	—	1	—	1
			2 yrs.	1	—	—	1	1	—
		Neuroma: 7 cases	under 1 yr.: 4 cases	3	1	1	1	2	1
		1 complete recovery	over 1 yr.: 3 cases	1	2	1	1	0	3
		Nerve constricted by scar: 5 cases	under 1 yr.: 2 cases (1 twice)	2	—	1	—	—	1
			1 yr. and over: 3 cases	3	—	—	3	2	1
			Total	22 complete motor		5 complete sensory		12 complete trophic	
Ulnar freed	12	Scar surrounding nerve: 8 cases	under 1 yr.: 2 cases	2	—	—	2	1	1
			over 1 yr. (under 2 yrs.): 5 cases (1 twice)	3	1	—	5	2	3
			over 2 yrs.: 1 case	1	—	1	—	—	1
		Neuroma: 3 cases	under 1 yr.: 1 case	—	1	—	1	—	1
			1 yr. and over: 2 cases	—	2	1	1	—	2
		Constricted by scar: 1 case 1 complete recovery	$2\frac{1}{2}$ mths.	1	—	1	—	1	—
		Total	1 quite complete	6 complete motor		2 complete sensory		3 complete trophic	
Musculo-spiral freed Post-interroseus, 1	7	Scar surrounding nerve: 3 cases 1 complete recovery	between 1 and 2 yrs.: 3 cases	1	2	1	2	1	2
		Scar invading nerve: 2 cases	5 and 25 mths.	1	1	1	?	?	1
		Nerve constricted by scar: 1 case 1 complete recovery	20 mths.	1	—	1	—	1	—
		Neuroma: 1 case	9 mths.	1	0	0	0	0	1
		Total	2 quite complete	4 complete motor		3 complete sensory		2 complete trophic	

Sciatic freed	6	Scar surrounding nerve: 7 cases	6–11 mths.: 4 cases	2	2	—	3	2	1
External popliteal freed	5		13 and 14 mths.: 3 cases	2	1	1	2	1	—
Both popliteal freed	1								
Internal popliteal freed	1		1 complete recovery						
Posterior tibial freed	3	Scar invading nerve: 2 cases	5 and 7 mths. 2 cases	2	—	2	—	2	—
			2 complete recoveries						
		Neuroma: 5 cases	6 and 10 mths.: 2 cases	2	1	—	2	1	2
			17 and 19 mths.: 2 cases	1	1	2	—	1	1
			1 complete recovery						
		Scar constricting nerve	17 and 19 mths.	—	1	1	—	—	0
			1 not improved						
			Total	5 complete motor		5 complete sensory		4 complete trophic	
Median and ulnar freed	10	Scar surrounding nerves: 5 cases	9–14 mths.	2	2	1	2	1	1
			1 complete recovery						
Musculo-spiral and ulnar freed	1	Scar invading nerve: 3 cases	7–27 mths.	—	3	—	2	—	0
Musculo-spiral and median freed	1	Neuroma: 4 cases	8–25 mths.	—	4	—	3	—	1
		Nerve constricted: 2 cases	8–16 mths.	—	2	—	2	—	2
Median, musculo-spiral, and musculo-cutaneous freed	1								
			Total	1 complete motor		1 complete sensory		1 complete trophic	
Total number of nerve freeings	79	Scar surrounding nerve: 34 cases	6 complete recoveries	17 complete motor		5 complete sensory		12 complete trophic	
		Scar invading nerve: 9 cases	1 complete recovery	5 ,, ,,		2 ,, ,,		2 ,, ,,	
		Neuroma: 19 cases	2 complete recoveries	7 ,, ,,		5 ,, ,,		4 ,, ,,	
		Constriction: 11 cases	2 complete recoveries	7 ,, ,,		4 ,, ,,		6 ,, ,,	
			1 not improved						
		Total	11 complete recoveries	36 ,, ,,		16 ,, ,,		24 ,, ,,	
			1 not improved						

TABLE III

Capacity for Work after Neurolysis

Nerve Operation.	*No. of Cases.*	*Presence of Complications.*	*Period since Operation.*	*Capacity for Work.* *Ordinary.*	*Light.*	*None.*
Median freed	32	Fracture or muscle adhesions : 20 cases	6 mths. : 5 cases	0	1	4
			between 6 and 12 mths : 5 cases	0	0	5
			between 1 and 2 yrs.: 7 cases	0	4	3
			over 2 yrs. : 1 case	0	0	1
		Uncomplicated : 11 cases	4 mths. : 1 case	0	0	1
			6–12 mths. : 5 cases	0	0	5
			1–2 yrs. : 7 cases	1	5	1
			over 2 yrs. : 1 case	0	1	0
			Total	1	11	20
Ulnar freed	12	Free or muscle adhesion : 8 cases	6 mths. : 1 case	—	1	—
			10–12 mths. : 4 cases	1	3	—
			over 1 and under 2 yrs. : 4 cases	1	2	1
		Uncomplicated : 4 cases	$2\frac{1}{2}$–16 mths.	1	2	1
			Total	3	—	3
Musculo-spiral freed	7	Fracture : 7 cases	1 yr. or under : 3 cases	0	0	3
		Persistent functional weakness : 3 cases	over 1 yr. (to 25 mths.) : 4 cases	0	4	0
Written reports only :						
Median freed	19	Fracture : 9 cases	3–21 mths.	0	5	4
		Uncomplicated : 10 cases	4–28 mths.	0	7	3
			Total	—	12	—
Ulnar freed	9	Fracture : 7 cases	3–18 mths.	0	4	5
		Uncomplicated : 2 cases	20 and 21 mths.	1	0	1
Musculo-spiral freed and 1 posterior interosseus	5	Fracture : 2 cases	6 and 12 mths.	1 (6 mths.)	1	0
		Uncomplicated : 3 cases	5, 7, and 15 mths.	0	2 (15 mths. (5 mths.)	1

Total. Median : 51 cases. 1 median at heavy work ; 20 median at light work.
Ulnar : 21 cases. 4 ulnar at heavy work ; 12 ulnar at light.
Musculo-spiral : 12 cases. 1 musculo-spiral at heavy work ; 7 musculo-spiral at light.
Sciatic or its branches : 26 cases. 4 sciatic at heavy work ; 14 sciatic at light.

TABLE III (*continued*)

Nerve Operation.	*No. of Cases.*	*Presence of Complications.*	*Period since Operation.*	*Capacity for Work.* Ordinary.	Light.	None.
Sciatic freed	6	Fracture: 1 case	7 mths.: 1 case	1	—	—
External popliteal freed	5	Uncomplicated: 14 cases	6 mths.: 3 cases	1	1	1
Both popliteal freed	1	(1 persistent functional	6–12 mths.: 4 cases	—	1	1
Internal popliteal freed	1	weakness)	1–2 yrs.: 7 cases	1	3	—
External tibial freed	2					
Written reports only:						
Sciatic freed	13	Uncomplicated: 15 cases	4–21 mths.	1	9	3 (2?)
Internal popliteal freed	1					
Posterior tibial freed	1					
Median and ulnar freed	10	3 complicated by fracture; 1 by tendon adhesions: 4 cases	7–27 mths.	1	2	1
Musculo-spiral and ulnar freed	1					
Musculo-spiral and median freed	1	Uncomplicated: 8 cases	under 1 yr.: 3 cases (8 and 9 mths.)	1	1	1
			1–2 yrs.: 5 cases	0	3	2
Written reports:						
Median and ulnar freed, 5	9	Complicated by fracture: 2 cases	9 and 15 mths.	0	2	0
Median, ulnar, and musculo-spiral, 2		Uncomplicated: 7 cases	6–24 mths.	0	4	0
Median and musculo-cutaneous, 1						
Median, ulnar, and musculo-spiral, 1						
More than 1 nerve	20			2	—	—
Total number of nerve freeings	128	—	—	14	68	46
		Fracture or adhesions of muscles: 59 cases		5	26	28
		Uncomplicated: 69 cases		9	42	18

TABLE IV

CAPACITY FOR WORK AFTER NERVE SUTURE (UPPER LIMB)

Nerve Sutured.	*No. of Cases.*	*Presence of Complications.*	*Period since Operation.*	*Capacity for Work.* *Ordinary.*	*Light.*	*None.*
Posterior cord of brachial plexus	2	Contracted shoulder: 1 case	21 mths.	—	1	—
		Uncomplicated: 1 case	15 mths.	—	—	1
Median sutured (examined)	15	Uncomplicated: 8 cases	under 1 yr. (6–8 mths.): 3 cases	1	1	1
			1–2 yrs.: 5 cases	—	5	1
		Complicated by fracture tendon adhesions or ulnar adhesions 7 cases	under 1 yr. (8–10 mths.): 3 cases	—	1	1
			1–2 yrs.: 3 cases	—	1	2
			over 2 yrs.	—	1	—
Median sutured (reports only)	17		under 1 yr.: 10 cases	4	3	3
			1–2 yrs.: 6 cases	0	5	1
			$2\frac{1}{2}$ yrs.: 1 case	—	1	—
			Total 32 cases	5	17	10
Ulnar sutured (without transposition)	13	Uncomplicated: 7 cases	under 1 yr.: 4 cases	1	—	3
			19 mths.: 2 cases	1	1	—
			31 mths.: 1 case	1	—	—
		Complicated by failure tendon adhesions or median adhesions 6 cases	under 1 yr. (7–11 mths.): 4 cases	—	2	2
			over 2 yrs.: 2 cases	—	1	1
Ulnar sutured (reports only)	10		under 1 yr.: 6 cases	2	2	2
			1–2 yrs.: 3 cases	1	2	—
			2–3 yrs.: 1 case	—	1	—
			Total 23 cases	6	9	8
Ulnar transposed and sutured (3 developed neuroma and were sutured again; too early yet for result)	20	Uncomplicated: 13 cases	under 1 yr.: 5 cases	1	—	4
			1–2 yrs.: 8 cases	1	6	1
		Complicated by fracture: 7 cases	7–12 mths.: 3 cases	—	1	2
			2 yrs. and over: 4 cases	1	3	—
Ulnar transposed and sutured (reports only)	14		under 1 yr.: 5 cases	—	—	5
			1–2 yrs.: 5 cases	—	2	2
			2–3 yrs.: 4 cases	—	2	2
			Total 34 cases	3	14	16

TABLE IV (*continued*)

Nerve Sutured.	*No. of Cases.*	*Presence of Complications.*	*Period since Operation.*	*Capacity for Work.* *Ordinary.*	*Light.*	*None.*
Median and ulnar sutured	1	Musculo-cutaneous destroyed	14 mths.	—	1	—
Median sutured ; ulnar transposed and sutured	4	Fracture : 1 case	15 mths.	—	—	1
		Uncomplicated : 3 cases	10 mths. : 1 case	—	1	—
			28 and 30 mths. : 2 cases	—	1	1
(1 ulnar done again, 3 with incomplete recovery of small muscles)						
Reported only	1		21 mths. : 1 case	—	—	1
Musculo-spiral sutured	14	Complicated by fracture : 6 cases	under 1 yr. : 2 cases	1	1	—
(2 had transpositions also done ; 1 failed to recover at all)			1–2 yrs. : 4 cases	—	3	1
		Complicated by median and ulnar lesion : 1 case	2–3 yrs. : 1 case	—	1	—
		Uncomplicated : 7 cases	10 mths : 1 case	—	—	1
			1–2 yrs. : 4 cases	1	2	1
			over 2 yrs. : 2 cases	—	2	—
Musculo-spiral (reports only)	4		under 1 yr. : 2 cases	—	0	2
			over 1 yr. : 2 cases	—	1	1
			Total 18 cases	2	10	6

N.B.—Transplant statistics are better than this.

Upper limb sutures	108		under 1 yr. : 49 cases	9	12	28
			1–2 yrs. : 42 cases	2	28	12
			2–3 yrs. : 17 cases	1	10	6
			Total	12 =11·1 %	50 =46·3 %	46 =43·6 %

Total at work 57·4 %

TABLE V

Lower Limb Sutures

Nerve Sutured.	*No. of Cases.*	*Presence of Complications.*	*Period since Operation.*	*Capacity for Work.* Ordinary.	Light.	None.
Sciatic sutured	6	Uncomplicated: 18 cases	under 1 yr.: 10 cases	—	2	9
Both popliteals	2					
Internal popliteal	3		1–2 yrs.: 6 cases	1	2	—
External popliteal	9		2–3 yrs.: 1 case	—	—	1
		Complicated by fracture: 1 case	22 mths.: 1 case	—	1	—
		(Internal popliteal adhesion, muscle injury)	7 and 12 mths.: 2 cases	—	—	2
Total	20					
Reports only:						
Sciatic	3		under 1 yr.: 13 cases	6	3	4
External popliteal (2 twice)	13		1–2 yrs.: 8 cases	—	1	7
Both popliteals	1					
Internal popliteal	3					
Posterior tibial	1					
Total	21					
Total lower limb sutures	41		under 1 yr.: 25 cases	6	5	14
			1–2 yrs.: 15 cases	—	4	11
			2–3 yrs.: 1 case	—	—	1
			Total	6 =14·5 %	9 =21·9 %	26 =23·6 %

TABLE VI

CAPACITY FOR WORK IN CASES OF LESION OF RIGHT UPPER LIMB

Nerve Operation.	*No. of Cases.*	*Heavy.*	*No. at Work. Light.*	*None.*
Brachial plexus freed	1	—	—	1
Median freed	13	1	5	—
Median sutured	9	0	5	—
Ulnar freed	7	1	3	—
Ulnar sutured	7	2	4	—
Ulnar transposed and sutured	15	—	4 (2 not using injured limb)	—
Median and ulnar freed	6	—	7	—
Median and musculo-cutaneous freed	1	—	(2 not using injured	—
Median, ulnar, and musculo-spiral freed	2	—	limb)	—
Median and ulnar sutured	2	—	—	2
Median sutured, ulnar transposed and sutured	2	—	1	1
Musculo-spiral freed	3	—	3	0
Posterior interosseous freed	1	1	—	—
Musculo-spiral sutured	6	—	6	—
Transplant for musculo-spiral	10	3	4	—
Other transplantations	8	—	4	—
Nerve grafts	2	—	—	2
Total where right limb involved	95	8 8·4%	46 48·4%	—
Total of both upper limbs		11·1%	46·3%	

TABLE VII

ANALYSIS OF CASES DOING ORDINARY WORK

Name.	*Lesion.*	*Nature of Work.*	*Time since Operation.*	*Presence of Complications.*
Brown	Median freed	R.A.M.C. orderly	3 mths.	o
Bulloch	Median sutured (forearm)	Infantryman	6 ,,	o
Davidson	R. ,, ,, ,,	'Old work'	6 ,,	o
Dean	R. ,, ,, ,,	Motor driving	7 ,,	Fractured rad.
Stagg	,, ,, ,,	Decorator	8 ,,	Fracture
Smithson	,, ,, ,,	'Old work'	11 ,,	o
Wilton	R. musculo-spiral sutured	Orderly	8 ,,	o
Warner	Ulnar sutured (axilla)	Baker's man	8 ,,	Elbow stiff
Ollerton	,, ,, (forearm)	Can lift 30 lb.	10 ,,	o
Hætherington	,, ,, (arm)	Mining engineer	22 ,,	o
Parker	,, ,, (forearm)	Electrical	11 ,,	Fracture
Scullion	,, ,, ,,	Infantryman	6 ,,	o
Haldane	,, transposed, &c.	Army officer	11 ,,	o
Patterson	,, ,, ,,	Fish trade	15 ,,	o
Aitken	,, sutured	Motor in mine	31 ,,	o
Clarke	,, and median freed	With caravan	9 ,,	Fractured rad.
Blackie	,, freed	Infantryman	2 ,,	o
Penny	,, ,,	Aeroplane factory	11 ,,	o
Smith	,, ,,	Van driver	17 ,,	Fractured rad.
Snow	Sciatic freed	Engine driver (mine)	9 ,,	o
Swan	External popliteal freed	Cycle mechanic	7 ,,	Fracture
Murnin	,, ,, ,,	Miner	9 ,,	o
Rimmer	,, ,, sutured	Sorter, post office	6 ,,	Fracture
Ball	Profundus transplant	Orderly	3 ,,	o
Jack	Sublimis ,,	Electrical engineer	11 ,,	o
Jenkins	Leg extensor ,,	'Any work standing'	8 ,,	o
Boyce	Wrist-drop ,,	Engineer	21 ,,	Fracture
Baxter	,, ,,	Joiner	18 ,,	,,
Lyons	,, ,,	Labour Company	30 ,,	,,
Mackie	,, ,,	Joiner	22 ,,	,,
Davis	,, ,,	Gardener	18 ,,	,,
Maloy	,, ,,	Painter (house)	7 ,,	,,
Fulton	,, ,,	Grocer's assistant	7 ,,	,,
Sanders	,, ,,	Infantryman	11 ,,	Elbow stiff
Vickers	,, ,,	Tram driver	11 ,,	Fracture
Campbell	,, ,,	Dock labourer	12 ,,	,,
Smith	Thumb-drop transplant	Infantryman	7 ,,	,,
Porter	,, ,,	,,	6 ,,	,,

Total 38—out of which 10 had transplantations for musculo-spiral paralysis.
Total cases reported on, 456.
Percentage at ordinary work, 8¼ per cent.

(N.B.—The times recorded represent those at which the patients were seen after the operations, or their reports received; not necessarily those at which they first began work, as we have been unable to ascertain the latter: i.e. they show the outside limit of time after which patients were fit for ordinary work.)

SPLINTS AND PLASTER

BY

D. McCRAE AITKEN, M.A., M.B., F.R.C.S.,

Surgeon, Special Military Surgical Hospital, Shepherd's Bush.

SPLINTS AND PLASTER

Splints have been used in surgery from time immemorial; in every age some additions have been made which have attained prominence for a time, not so much from any inherent virtue in the splint itself as from the masterly manner in which it was used by its inventor. In most schools of medicine the use of certain splints has become traditional for particular fractures, and the tradition has sometimes continued in spite of the introduction of more convenient splints.

In the present article it is only possible to discuss the principles underlying the uses of splints, and the adaptability of splint materials to those uses, with a brief reference to some of the special forms which have been in common use during this war.

The association of ideas, which the traditional use of particular splints for particular fractures tends to foster, is one which is detrimental to surgical progress. The surgeon must know exactly in what position he desires to fix an injured limb and why, the choice of wood, metal, or plaster of Paris can then be made by him according as he finds one or other most suited to his purpose; it will, nevertheless, be found convenient to keep certain simple types of splint in stock ready for immediate use.

A definition of a splint which will properly convey an idea of its purpose and use is not easy. When a student, the writer once heard Professor Chiene in Edinburgh say that 'pain is Nature's splint by which she enforces rest'. Taking a hint from this aphorism, it may be said that a splint is a mechanical substitute for pain. If this definition is examined as a divine would expound a text, it will be found to contain a great part of what a splint should be in practice when applied to an injury of bone, joint, muscle, or ligament. Thus a splint is used to enforce rest of an injured or inflamed limb, just as rest is enforced by pain; second, if the splint is successfully applied, pain should be relieved, that is, it must be a substitute for pain; in the third place, the use of a splint is still required so long as it is acting as an effective substitute for pain, that the return of pain when a splint is discarded is generally an indication that the part still requires mechanical support to complete its repair, and some form of splint or support should be continued.

In the treatment by splints of injuries of the limbs not complicated by inflammation and the pain due to inflammatory tension, freedom from pain should be regarded by the surgeon as one of the important tests

whether he is using the splint properly. For example, if the morning after a recent Colles's fracture is set the patient complains of pain, the surgeon should consider whether he has fully reduced the fracture or if he has not applied the splints correctly. If everything were correct the patient should express surprise that his pain is so little rather than complain that it is so great.

An example of pain due to leaving off splints too soon is to be found in Pott's fracture. It is common in orthopædic practice for the surgeon to be consulted about pain in and about the ankle three months after the fracture. The history frequently is that the fracture was perfectly reduced and set, and that the patient could walk without pain in six or seven weeks, but a few weeks later on returning to work or commencing games pain recurred. On examination the pain is usually found to be most acute at the seat of fracture in the fibula and perhaps at the tip of the internal malleolus. It is almost invariably relieved by 'crooking' the heel of the boot and making the patient wear an outside iron with inside T-strap to maintain inversion of the foot, for this relieves the strain on the callus. The return of pain should be an immediate indication to the surgeon that a splint is still needed, in a case such as this.

Splints may be divided into three groups :

1. Splints for local fixation, which generally depend for their efficiency on the way in which they can be made to fit the contours of the limb.

2. Splints designed to maintain a special position, which must be comfortably fitting at the *points d'appui* but need not necessarily fit the limb closely at other points. These include splints such as are used for maintaining abduction in injuries about the shoulder or the hip, dorsiflexion of the wrist, lateral braces at the ankle.

3. Splints whose immediate purpose is to apply a stress so as to strain a deformed limb into some new or more correct position. This group includes such familiar examples as knock-knee and bow-leg braces, and the more recent development of splints for gradually mobilizing stiff joints.

It is quite impossible to make these mutually exclusive, for example a bone injury may be such that the surgeon would prefer to use close-fitting local splints, but on account of a local septic wound must employ some skeleton device which will allow access to the wound without removing the splint. In orthopædic practice in dealing with injuries which have produced or are potential of producing deformity, the practitioner has an opportunity of exercising his skill and ingenuity in surgery which after all only means handicraft (χειρουργία).

Material for Splints. The choice of the material of which splints are made, and the choice of the type of splint to be used, will always vary to

some extent with the training and practice of the surgeon. The writer is conscious of a bias in favour of those splints with which he is most familiar, but as he was brought up in a school of wooden splints, supplemented occasionally by plaster of Paris, and has transferred his allegiance to one of metal splints and plaster of Paris, he may at least attempt to give some reasoned explanation for his later preference.

First of all let it be said that there is scarcely anything new in splints. They have been found in ancient tombs made of strips of wood laced side by side or woven together like the well-known Gooch material. Again, Ambrose Paré, in the fifteenth century, used splints of sheet metal, notably a wrist splint to maintain dorsiflexion of the wrist almost identical with the splint used by Sir Robert Jones ; he also ' crooked ' the heels of his patients' shoes with wedges of leather. The writer possesses an old print illustrating splints used by Buzaglo about 1775 for inflammation of joints, in which the shoulder- and hip-joints are shown in abduction and the ankles at a right angle. His work seems to be forgotten, and his book on arthritis is apparently very rare. It may therefore be assumed that in this, as in other things, history repeats itself.

Splints for various purposes have been made of wood, metal, leather, various compositions, and plaster of Paris.

Wooden splints have long been in common use for local splints, and in their simple form consist of flat boards which are padded before application. The only advantage to be claimed for them is that they can be cut with an ordinary knife. Their disadvantages are, first, that a flat board cannot be made to fit closely to a rounded limb, the flat surface must always be merely a tangent to a cylindrical or conical limb, if any attempt is made to bandage such splints tightly on to the limb there is always a line of maximum pressure, with all its attendant risk of pressure sores. However skilfully the surgeon may pad the splint he has always to run the risk of producing a pressure sore if he is to apply the splint tightly enough to control a misplacement or run the risk of movement of the parts within his splints if he does not fix them tight enough.

Gooch splint material was introduced in an attempt to obviate this. It consists of parallel slips of wood on a canvas basis, which can be curved laterally into a cylinder but not into a cone. It can therefore be used fairly well on the thigh or arm, which are cylindrical, but cannot be made to fit so well on a conical part such as the forearm or leg.

Wooden splints are usually about ¼ in. thick, which is bulky and awkward. For example, Gooch splint wrapped round the humerus as a local splint is uncomfortably bulky in the axilla.

In many places the splints of sheet metal have entirely superseded wooden splints for all ordinary purposes. The splints are of various

sizes from 3 in. to 24 in. in length and varying in width from about 2 in. to $4\frac{1}{2}$ or 5 in. When supplied to the surgeon they are slightly curved laterally. This gutter shape gives even thin sheet iron great rigidity in the longitudinal direction.

The advantage of such a splint is first that, on account of its curved shape, the pressure of the splint is distributed over a considerable surface of the limb, so that it can be applied very firmly to maintain correct position of the limb without fear of causing pressure sores.

In practice sheet iron of No. 22 or No. 24 Birmingham gauge will be found the most convenient thickness when using soft sheet iron, as this is not too stiff to be bent easily by hand while being applied. In applying such splints to a conical limb such as the leg one end can be more curved than the other so as to make the splint fit the conical limb. Further sheet metal can be twisted spirally in the longitudinal direction so that it may more accurately fit the curve of a limb ; for example, when applying local splints to assist in controlling a fractured femur it is often convenient to give the splint a slight spiral twist to follow the curve of the femur.

Such thin metal is no more difficult to cut than wood, provided the surgeon has an ordinary pair of tin-smith's shears so that when need arises he may cut and adapt the sheet metal to his use. The thinness of the metal is also an advantage, as it occupies less space than wood, and being adapted to the shape of the limb needs very little padding, which adds to the security of the grip. When the splint extends over a bony prominence such as the condyles of the femur, the hollows of the limb above and below the condyles should be well padded, so that the splint may not press on bony points.

Perforated zinc splints can be used for the same purpose. In dealing with the compound fractures following gunshot injuries it was often possible to apply perforated zinc splints direct to the limb and irrigate the wound through tubes passing through holes which can easily be made, if need be, with an ordinary pair of scissors. In dealing with fractured femur with large wounds, the writer's practice was to place such a perforated splint at the back of the limb, and, when necessary, other local splints of perforated zinc laterally in addition to the usual fixation in a Thomas knee splint. There were thus no dirty dressings to remove, free irrigation washed away the discharges, and there was no occasion for the limb to be moved.

The usual fixation of a simple fracture of the shaft of the humerus is with three splints. The outer splint extending down as far as the external condyle and being bent over the shoulder like a shoulder-cap. Two small splints, one below each axillary fold on the inner side of the limb suffice to encircle the limb completely; all that is required besides this is to flex the elbow to about 60° and sling the wrist from the neck. It

is only necessary to bandage the arm to the side for a few days; after this the patient is quite comfortable in these splints with the arm inside his shirt.

In dealing with gunshot fractures it was sometimes possible to use perforated zinc splints in the same way, relying on irrigation instead of dressings. Absorbent dressings being applied outside the splints. The disadvantage of some skin irritation has to be set off against the great gain of more perfect local fixation, when dealing with large very septic wounds.

If compound fractures are left securely fixed and properly at rest with free drainage and irrigation, the patient's temperature should as a rule fall, and there is good opportunity for definite repair.

Once or twice during the war, whole series of gunshot fractures were found running irregular temperatures in wards under the writer's charge; in each case an over-zealous medical officer or sister was taking off local splints in order to get at wounds, thus disturbing repair, breaking granulating surfaces, and allowing absorption of toxins from the wound. When they were persuaded to leave the limbs at rest the epidemic of charts with irregular temperature graphs ceased. The merits of local splints which are not removed to dress wounds are also obvious when wounded men are being transported. Repeated irrigation instead of removing of dressings is much less painful and less exhausting to the patient.

When there are no wounds to be considered and the surgeon is satisfied that the limb is in correct position, plaster of Paris is undoubtedly the best fitting and most effective of all local splints, and if properly applied can be used also to maintain correct position of joints, or be used as an ambulatory splint. In the presence of copious discharge, plaster of Paris is apt to get very foul, and dressing of wounds through windows in the plaster is difficult to manage satisfactorily.

Splints to control position of the limb form the second general group of splints. These splints are few in number and are those designed for particular purposes.

In the upper limb there are three in constant use:

1. Splint to fix the shoulder in abduction.
2. Splint for the elbow.
3. Splint for the wrist.

The abducted position of the shoulder is so often essential in the treatment of injuries in or near this joint that several attempts have been made to design splints which could be kept in stock. Of these none has proved satisfactory, for no matter how comfortable the splint may seem when the surgeon tries it on himself, it is a very different thing

when put on a patient with a painful shoulder-joint. No removable splint which has to be fastened on with straps and buckles can keep the shoulder steady enough ; hence, all surgeons seem to be united that the only means of securing good fixation is in plaster of Paris. Removable splints may be worn at a later stage when the patient is allowed to exercise the shoulder, but even then a removable plaster splint is often found more comfortable. While the patient is in bed it is possible to fix a splint

FIG. 162.—Note perforated zinc on which this case was originally treated has been incorporated in plaster without removing it, thus allowing the patient to sit up.

built of perforated zinc or other metal, but when the patient can sit up these must be supplemented by plaster of Paris to give the necessary steadiness (Figs. 162, 163, and 163 A).

Of splints to control the elbow, the old internal angular wooden splint, even if it has a hole to accommodate the internal condyle of the humerus, can only be condemned as a bad splint. It should not be used for fractures about the elbow-joint, for the correct position for these fractures, with the exception of fracture of the olecranon, is with the elbow fully flexed. Moreover, this splint is very apt to cause tilting of the lower fragment

outwards in supracondylar fractures, and in all cases the forearm is bandaged to it in semipronation instead of in full supination.

In cases of injury at the elbow with open wounds in which it is not possible fully to flex the joint at once, a posterior angular splint with a gap for dressing the wound is generally the best, for the forearm can be laid in it in full supination.

The wrist splint to maintain dorsiflexion is now in general though

FIG. 163.—Same case in plaster at a later stage.

not universal use. Whatever it be made of, whether sheet metal with a palm piece turned up, or a ball for the palm of the hand fixed on the end of a straight forearm piece, it should be so designed that the thumb can be put in a position of opposition, that is, the position it is in when picking up a tumbler of water (Figs. 164, 165 A, and 165 B).

In the lower limb, abduction of the hip, extension of the knee in knee injuries and the right-angled position of the foot, are the positions which must be maintained in injuries in or near the hip, knee, and ankle, in order that the limb may be in the best position for walking, even should the joint become stiff.

Abduction of the hip, if there is no fracture of the femur, can be best secured by fixing the thigh and pelvis in this position in plaster of

Paris, and unless there is active disease or inflammation of the joint, the patient may safely walk in this.

Often, however, the surgeon desires to keep the region of the hip under observation or free for dressing of wounds, or on account of a fracture of the femur in its upper fourth he desires to maintain extension in an abducted position, in which case he must either have his patient on

FIG. 163 A.—Removable shoulder abduction splint of metal. Case shown was one of compound fracture right across the body and spine of scapula. On arrival the surface wound was circular and larger than a saucer. This splint lifted the outer fragment. The scapula united and the wound is seen healing as a linear scar in the line of the fracture.

an abduction hip splint such as the Thomas hip splint with abduction or rely on fixing the limb out to some part of the bed or to some erection or framework of the Balkan splint family. If he uses one of the latter, then his patient is fixed to the one bed till the necessity for fixation is over, which may be many weeks ; if, however, the patient is fixed on a Thomas abduction splint, the splint and patient are an independent unit which can be moved without hesitation.

The use of this splint seems to have been found inconvenient and

troublesome by some who have tried to use it during the war, while to those accustomed to its use, it is a haven of refuge whenever the nursing of a patient becomes difficult on account of the severity of his wounds. One reason for the difficulty experienced is that many of the abduction frames have been faulty in design and in construction. The first common fault is that the two vertical bars of the splint are too wide apart, and the second is that the leather pad or saddle has been too soft and usually the gap left for sanitary purposes has been too wide. The result of these two faults is that the pelvis slips back between the bars, and therefore the alinement of the pelvis, hip, and thigh is distorted.

The two vertical bars in a correctly made splint are surprisingly close together, and should be just external to the posterior superior spines of

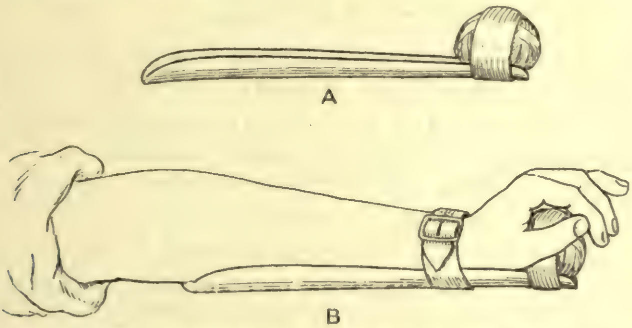


FIG. 164.—'Ball' splint for gradual dorsiflexion of stiff wrist, consisting of a ball of wadding wrapped in bandage and fixed to gutter-splint with strapping. A. The splint. B. The splint in position, showing free position of thumb.

the ilium. Next the back pad or saddle should be packed with lamb's wool so evenly and so firmly that the metal-work is not felt through it. If these two points be attended to, pressure on the sacrum is avoided and there is no difficulty from sores.

The next point is that medical officers, sisters, and nurses who are not familiar with the splint often undo the groin strap or extensions to get at wounds or turn the patient to get at his back. If there is a wound in the back a window should be cut in the saddle for dressing it ; if the splint is required it should not be loosened or undone except at rare intervals and then by the surgeon.

The management of the groin strap, usually taking a purchase on the opposite tuber ischii, is the same as that of the ring in a Thomas knee splint. When first put on, the nurse or attendant must pull the skin first to one side of it and then to the other at frequent intervals ; in rare cases it may require attention every half-hour for the first twelve hours till the skin begins to get used to the pressure ; after the third day attention once or twice a day is usually sufficient, but the strap

itself should never be undone. If the skin begins to show signs of redness, the nurse at once passes a sheet of note-paper dipped in pure castor oil between the skin and the strap ; any attempt at padding with wool is fatal as it both hastens the formation of a sore and does away with the efficiency of the extension. The back should never be washed with water ; the method of keeping it is to polish it with soap, as an ostler polishes a saddle. What is required is a dry rag ; this is rubbed with a wet cake of any good soap. The back and the saddle are then polished by the nurse passing the hand covered with the rag between the back and the saddle without lifting or turning the patient. Spirit is rarely needed, and is apt to make some skins crack. The groin strap is similarly polished by drawing a fine handkerchief rubbed with soap between it and the skin. The gap in the saddle should be adjusted so as to come opposite the lower segments of the sacrum ; patients are sometimes put too low on the saddle, and this lets the sacrum slip down between the two thigh wings and pressure sores on the sacrum or crest of the ilium are the result. The pelvis must not be allowed to fall backward behind the plane of the thigh, or there will be distortion at the hip, or at the seat of injury near it.

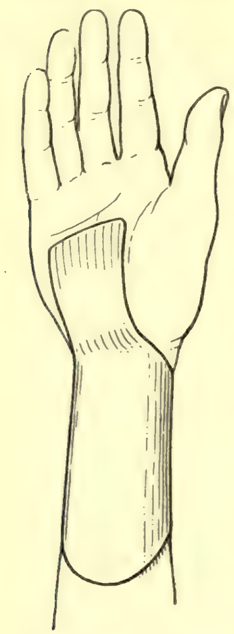


FIG. 165 A.—Showing shape of palm-piece of small cock-up splint in relation to lines of the palm.

This splint is useful not only in fractures and joint injuries at the hip, but is also a universal splint for all spinal injuries or conditions in which it is essential or desirable to keep the trunk steadily at rest.

The Thomas knee splint has come into its own in the course of the war as a general splint for controlling the position of the lower limb. Many modifications of it have appeared, notably the flexion at the knee which is figured in one of Owen Thomas's own books published in the seventies of last century.

Owen Thomas's injunction to the surgeon not to attempt modifications of the splint until he has mastered the use of the splint in its standard form, still is as valuable as when it was written in 1878. It is noteworthy that those who have been educated in the Liverpool school have adhered to the straight Thomas knee splint throughout, especially at the hospital at Alderhey, where I believe the results of fractured femurs will bear comparison with those of any other hospital.

The splint can be used to immobilize the lower limb for any injury below the lesser trochanter down to the ankle. Local splints are necessary

to control the actual seat of injury; in the thigh, knee, or leg local posterior support is especially required to prevent backwaıd sagging. The Thomas splint is essentially one for securing general position of the lower limb, giving fixed points for immovable extension, and above all for secure transport without hurting the patient or producing shock.

The essential points in the management of the splint are: first, the size of the ring. The ring should be an easy fit, and it does not matter if its circumference is considerably more than that of the limb. The thickness of the padding on the ring is very important. The padding should be as thin as possible, a diameter of an inch or an inch and an eighth should be the maximum. The writer has seen many splints with padding too thick for comfort and security, never one with padding too

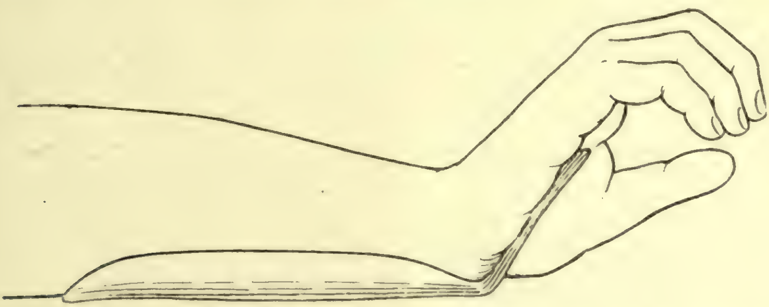


FIG. 165 B.—Small cock-up wrist splint, showing thumb free in position of opposition.

thin to be used. The stouter the patient the thinner the padding on the ring, or it will not lodge on the tuber ischii but will slip up into the permeum.

The management of the skin has already been described.

In nursing children with diseased knees the rule has been handed on through a succession of sisters and nurses that even the smallest child should never be lifted by one nurse. It takes one nurse to lift the splint and limb, one hand taking hold of the front of the ring and the other of the lower end of the splint; the splint and limb is lifted by one nurse while the other lifts the rest of the child. If this is neglected the ring slips off the tuber ischii, and then the limb rotates with immediate displacement of parts, loss of effective control, and pain. Many surgeons found this out when using the splint for war injuries, and devised various means of slinging the ring, as well as the lower end of the splint, from overhead frames to facilitate movement of the patient without displacement of the splint.

Local splints in conjunction with the Thomas knee splint are of great

practical value. For example, in dealing with excisions of the knee, it is nearly always necessary to change the dressing soon on account of the oozing of blood, and this is an excruciatingly painful process for the patient if not carefully done. Local splints of perforated zinc, or some such material, boiled before the operation and twisted to lie comfortably against the sides of the thigh, knee, and leg, should always be used. Two pairs of hands are necessary for the dressing. The Thomas splint is, of course, not removed; one lateral local splint is removed while an assistant holds the limb steadily against the other. The dressing being changed and the local splint removed, the other side is dealt with in the same way. With attention to these details the most difficult cases can be dressed without anæsthetics and without pain or shock. It takes about twenty minutes to do a first dressing of an excision of the knee in this way, but the time is well spent.

With regard to fixation of the foot at a right angle, there is only one practical point which requires note because it is so often omitted, and that is care of the transverse arch of the foot.

If a foot is to be bandaged for a long time to a flat foot-piece, a bar or pad of felt should be placed in the hollow just behind the heads of the metatarsals. It helps to preserve the transverse arch and allows free flexion of the toes, the loss of which is an important contributing factor in painful conditions of the ball of the foot, associated with flattening of the transverse arch.

Splints used to correct deformity are of two types: first, those where the mechanical device of the splint is used to exercise corrective force; and second, those in which the splint is used to divert body-weight so as to utilize it as a corrective force. The latter type belong entirely to the splints of the lower limb. Elbow splints to restore movement when the joint is stiff from dense fibrous deposits in and about the joint, have been used with some success. The principle of the splint is the same as that of the Turner knee splint for the same purpose. The splint consists of lateral bars hinged opposite the joint. The bars are connected to roughened pieces of sheet metal curved to fit the limb above and below the joint. A light casing of plaster is first applied and then the splint is incorporated in the plaster (see Figs. 166, 167). The joint in the splint is actuated by a powerful screw. The practical difficulties in the use of these splints are great. The screw's action is powerful, and no matter how carefully the plaster casing on the limb is applied the pressure on the skin by the powerful thrust of the screw is great and very apt to produce pressure sores. The use of these splints seems to be waning, either because the cases in which they were found useful are now not so numerous or because surgeons have found that patient perseverance in other methods brings equally good results. The writer certainly used them very little

in 1919, though he tried them frequently in 1916 and 1917. Experience has shown that when flexion for instance is limited by fibrous ankylosis, it is possible gradually to clear a small range of movement merely by putting the limb into the position of maximum flexion possible and fixing it there in plaster for about a week. After the plaster is removed move-

FIG. 166.—Screw elbow splint. Note that the plaster casing is continued up to the shoulder and down to the hand. If this is not done, the splint shifts when screwed up and sores are more likely to occur.

FIG. 167.—Turner's screw splint for the knee. Note that the plaster extends up to the tuber ischii, which is padded with felt, and below includes the foot. This is essential to get firm points of purchase.

ment may be possible voluntarily through a few degrees ; after a few days the muscles get stronger and the movement more controlled, but the range of movement is diminished. The limb is then again flexed and fixed, and again released for exercise. In this way with patience, steadily increasing movement can gradually be restored in elbows without

pain and without pressure sores. Hence the attempts to get more rapid results by forcing the pace with screw splints have gradually been abandoned.

This is particularly the case in dealing with stiff joints in the wrist and hand. Flexion at the wrist with apparently firm fibrous union of the whole carpus will generally yield to gradual correction in splints.

In all the splints used the part for the palm of the hand is more or less convex so as to fit into the hollow of the hand. In its simplest form the wrist splint consists of an anterior gutter splint extending from below the elbow to the palm. On the end of this a firm ball of wool, felt, or other suitable material is fixed. The ball is placed in the palm of the hand and the splint applied along the anterior aspect of the forearm. A strap and buckle round the wrist allow the patient himself gradually to tighten the grip on the wrist thus forcing the wrist-joint into dorsiflexion. In some hospitals these splints have been made of wood with a wooden hemisphere on the end. The advantage of a ball of wool or felt is that the surgeon can regulate the size of the ball to suit each case, and generally the size of the ball has to be changed about once a week as movement is gradually restored (Fig. 164).

Splints have been specially devised to overcome the obstinate dorsiflexion of the metacarpo-phalangeal joints so often seen as the result of wounds of the forearm and hand.

In the treatment of such cases the wrist must be first dorsiflexed and the interphalangeal joints straightened gradually before the metacarpo-phalangeal joints can be effectually dealt with.

The actual flexion of the hyperextended metacarpo-phalangeal joints may then be attempted. In doing this two different methods are employed. The splint devised by Verrall consists of a bridge attached to a small cock-up wrist splint. The splint is applied firmly to the dorsiflexed wrist with plaster of Paris. Small extension or traction tapes are attached to the fingers with adhesive plaster and the tapes are tied to the bridge. It is to be noted that the pull in this splint is practically at right angles to the axis of the proximal phalanx.

Baldwin, an American surgeon working in Edinburgh, maintained that it was first necessary to exercise traction on the stiff joint before flexing it, on the ground that by so doing the stiff capsules are first stretched and loosened and are then more easily flexed.

The hand-piece on his splint was wood of an ovoid shape, which gives a comfortable pressure in the palm for counter resistance when the extension strings on the fingers were tightened. The bridge to which extension was taken was therefore made adjustable, so that extension could first be made in the line of the fingers and later in more and more flexed positions.

In the case of the lower limb various ambulatory splints can be used either to give security or to deviate the body-weight in such a way as to make it a force to correct the deformity.

Among walking splints the Thomas walking calliper or the walking knee splint is one which can be used for a large number of purposes. Devised originally to keep the knee steady and to carry the body-weight from the tuber ischii direct to the socket in the heel of the boot, it has become a general utility splint to enable a patient suffering from any weakness in the lower limb to walk with safety. Thus old people with ununited intracapsilar fractures of the femur can walk without crutches in this splint. One of the most successful forms of treatment for ununited fracture of the shaft of the femur is to let the patient walk in a calliper with of course local splints as well. Cases of delayed union or non-union of the tibia can be fitted with this splint and enabled to get about and attend to their affairs, till a sufficient interval has elapsed after the sinuses are closed for an aseptic operation to have some prospect of success. At the same time the side bars can be used if need be as lateral braces to correct valgoid or varoid deformity at the knee or at the seat of a fracture. The patient sits on the ring which should fit fairly closely, and the other end of the splint is fitted into sockets in the heel of the boot (Fig. 168).

Another variant is of use in cases of mal-union of the femur with gross shortening, as it makes the patient independent of crutches till it is safe to operate (Fig. 168 A).

The recognized measurements to give the instrument-maker are the horizontal circumference of the limb at the level of the tuber ischii, and the length from the tuber ischii to the bare heel. The instrument-maker allows 3 to $3\frac{1}{2}$ in. more on the ring according to size so as to make it fit when set at an angle of about $45°$ to the horizontal.

Braces below the knee are used sometimes as a guard when the patient first walks after recovery from a fracture of either of the bones of the leg at or below the middle, more often to deviate the body-weight and correct varus or valgus deformity at the ankle.

A brace below the knee is not efficient as a guard for a fracture in the upper half of the leg. In these cases it is better either to put the leg and knee up in plaster or let the patient have a walking calliper till the bones are hard enough to carry the body without any assistance.

A double brace, one on each side of the leg, is very rarely necessary. It is the writer's opinion that no matter whether the fracture in the leg has been one of the fibula only or of the tibia alone, or of both bones, the surgeon should always order an outside iron and inside T-strap unless he has a very definite reason, such as a pronounced varus of the leg, for ordering an inside iron. The danger of flat foot occurring is much greater

than the danger of a varus; therefore it is good practice to order an outside iron even for a fracture of the tibia alone—unless there is a definite reason against it.

Plaster as a Splint Material. Plaster-of-Paris bandages can be used as a substitute for nearly every splint in use, provided there is not too

FIG. 168.—Thomas walking calliper splint.

FIG. 168 A.—Patten Thomas walking splint. The patient shown had 5 in. shortening of the femur from mal-union. He went home and walked in this splint for six months after his sinuses were healed, and then returned for operation. Result was 1 in. real shortening.

much discharge from wounds. When it is desired to keep a limb fixed in one position for weeks, plaster properly applied is at once the most comfortable and the most efficient of splints.

The plaster of Paris must be of good quality, well burnt, and must be kept in a warm dry place.

The bandage material which has been found best is cotton muslin, and the most suitable quality is that known to the trade as No. 14 Manchester make. The most suitable sizes of bandage are 4, 6, and 8 in. wide, 4 or 6 yards long. When the muslin is torn into strips to make the bandage, two threads must be drawn at both edges of each bandage. If this is neglected loose threads get entangled, and the wet bandage will not run truly while being put on. Handmade bandages are much better than machine-rolled bandages. The plaster is rubbed into the muslin by hand as it is rolled; the bandages must not be too tightly rolled or the water will not get well into the centre. Finally, the bandages for each day's work should be made not more than twenty-four hours beforehand if possible. Stock bandages sold in tins in shops are of very little use.

The application of plaster requires practice and a trained muscle sense, for plaster sets so quickly that it must be applied quickly and with the requisite degree of pressure. Just as there are some people who seem never able to drive a nail in straight, there are some who never seem able to apply plaster bandages effectively. There are some leading points which may be stated in print, but practical experience is the only real school.

First, the limb must from first to last be kept in the position in which it is to be when the plaster is set. Any movement, once the plaster has begun to set, means a crack in the plaster.

The limb may be covered first with a stocking or tube of stockinget; this adds to the comfort of the patient; if no pressure to correct deformity is required, plaster may be applied direct over two or three layers of stocking. Usually it is necessary to apply a layer of wool; this should be uniform. The wool should be unbleached, non-absorbent wadding—absorbent wadding gets wet and packs into a hard mass at once. The most convenient is unbleached wadding sold by drapers for padding the shoulders of coats; this is sized on one side. It therefore can be rolled like a bandage and applied to the limb like a bandage. Wadding, without a sized surface, breaks too easily and will not run like a bandage. It is a mistake to apply an ordinary bandage over this, for experience has shown that it is apt to shrink or have a tight turn which interferes with circulation.

The plaster bandage should be put in a large bowl or pail of water until all bubbles of air have escaped and then used at once; therefore only one bandage should be put in the water at a time. The bandages must be put on firmly and evenly, covering the whole work uniformly at first until three or four layers have been applied; special strips to give extra strength where needed may then be worked in. It should be remembered that plaster shrinks a little as it sets—the amount of wool should

FIGS. 169 and 170 show state on admission of a patient who had been hit in the back by an 8-in. 'dud' shell, which had damaged spines of several vertebrae and muscles of the back. Two attempts had been made to suture the muscles, but no sort of spinal splint had ever been used.

be just enough to allow for this, so that the plaster fits at the end. Interference with circulation when it occurs is always due to one careless turn which is drawn too tight or to reversing the bandage. Once the deeper layers have begun to set superficial layers may be put on tighter, but no

FIG. 171.—The same patient in the third of a series of plaster jackets in which his back was gradually straightened.

FIG. 172.—Thomas posterior spinal support in which patient left the hospital, to take up an appointment in civil life.

liberties may be taken with the uniform application until a firm covering is obtained.

The illustrations show various types of plaster splints whose purpose is explained in the accompanying text. The pictures show that plaster may be used to fix jointed splints to the limb. To support a shattered limb leaving wounds supported on intervening perforated zinc splints.

FIG. 173.—Showing puckered scar in calf muscles, and the best position of the foot about 105°, i.e. some degree of equinus deformity at the ankle.

FIG. 174.—First stage of 'drop-heel' plaster, showing traction bands to keep foot as near a right angle as possible.

In bad compound fractures of the leg perfect fixation can sometimes only be obtained by encasing the thigh and knee in plaster and the foot in a separate shoe of plaster, the gap being bridged with three stout bows of metal. This allows the wound to be irrigated or dressed without removal. Sometimes the whole limb, plaster and all, was supported in a Thomas splint to give extra security.

In making bridges of this type it is often convenient to use strips of thin sheet metal because the surgeon can shape these by hand. If a plaster bandage is wound round the metal after it is shaped and the whole fixed in while wet, it sets quite rigidly. This is often much more easy to manage than thick metal, which can only be shaped in a workshop.

Plaster Spica for Thigh and Pelvis. This plaster splint, intended to fix the upper end of femur and hip-joint generally in abduction, is used first in diseased conditions of the joint, and second as an ambulatory plaster for fractures of the upper end of the femur.

To apply this spica properly a pelvic rest is necessary, as shown in the illustration. The upright post is placed against the tuber ischii. The support for the head and shoulders may be improvised, but the pelvic rest is an essential for which there is no substitute. There are special tables for plaster work containing this and other conveniences, but this is the only essential for which no effective substitute can be found in a hurry.

The last special plaster splint illustrated is one by which the body-weight is used to stretch scars in the calf. Several other surgeons have adopted this device and have reported favourably of its success.

The object is to cure the patient of walking in an equinus position without dividing or elongating the tendo Achillis, for if the scar in the muscle can be stretched a greater range of movement and greater strength can be obtained.

The photographs and diagrams illustrate the procedure. The first photograph (Fig. 173) shows the limb with puckered scar and the foot in its best position about 105° with the leg. The limb is padded with wool in the usual way, and a thick bar of felt, an inch or more in width, is placed across the sole just behind the metatarsal heads to ease the pressure on these bony points. A close casing of plaster is then applied nearly up to the knee. The second photograph (Fig. 174) shows a threefold or four-fold band of plaster on which an assistant is pulling to maintain the fullest possible dorsiflexion, while it is first secured by circular turns of plaster bandage below the knee, and the tension on it is increased by bowsing it down to the leg, as shown in the third photograph (Fig. 175)—note the bump on the sole where the felt pad is situated. The plaster is then allowed to set. When it is set, the whole of the portion covering the heel and malleoli is cut away, as shown in the first diagram (Fig. 179); the narrow

FIG. 175.—Showing the traction bands being lashed down to the leg with circular turns of plaster bandage.

FIG. 176.—Showing how the first plaster case is cut out to set free the heel and malleoli with padding of loose wool. Note the metal bow to be put over the heel.

FIG. 177.—The metal bow in position.

FIG. 178.—The 'drop-heel' plaster finished.

isthmus left in front contains the tension bands, and is therefore strong enough to retain its rigidity and shape. The next photograph (Fig. 176) shows the gap in the plaster and a large lump of very loose wadding placed under the heel, and a bent piece of iron ribbon $\frac{3}{4}$ in. wide and $\frac{1}{8}$ in thick, which is shown in position in Fig. 177. The whole is now

FIG. 179.—Diagram of drop-heel plaster. The shaded part is the portion of the first plaster case cut away to free the heel. D is the felt bar.

encased in more plaster, taking care not to compress the loose wool. The completed contrivance is shown in Fig. 178.

The mechanism is shown in the last diagram (Fig. 180).

Before the splint was applied the man stood barefoot on the ball of the foot, as on the line EE, with his heel off the ground. Walking thus on tiptoe, he keeps his centre of gravity plumb over the ball of the foot.

With the plaster on the only part of the splint which touches the ground FF, is the bottom of the iron at D. In order to stand he must keep his centre of gravity back over the point C and the weight of his body, acting along the line of the arrows A, thrusts his heel down into the

loose wool below the heel. The fore part of the foot is held up in the direction of the arrow B by the strong fore part of the plaster. The foot therefore acts as a lever at every step he takes, gradually stretching the short calf muscles.

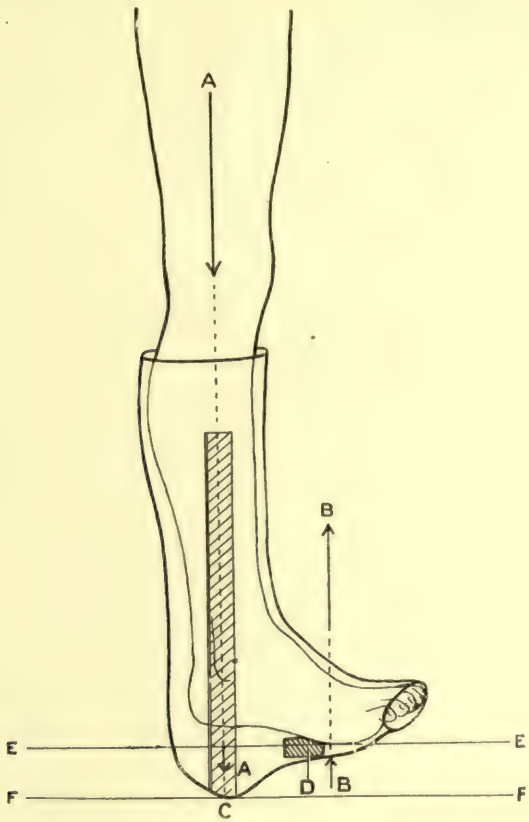


FIG. 180.—Diagram illustrating mechanism of drop-heel plaster.

EE represents the ground-line on which the patient walked on tiptoe before treatment.

FF is the ground-line on which he walks in the plaster splint.

Arrows AA show the line along which the body-weight is transmitted downwards to the ground at C, where the iron bow rests on the ground. The patient must keep his centre of gravity over this point in order to balance. Thus the heel is thrust down into the soft pad underneath it.

D represents the felt pad.

Arrows BB show the line of upward thrust on the ball of the foot as the heel sinks under body-weight.

PLAIN METAL SPLINTS

BY

R. LANE JOYNT, M.D., F.R.C.S.I., Lt.-Col. R.A.M.C.

Assistant Inspector of Military Orthopædics. Surgeon to the Meath Hospital, Dublin

PLAIN METAL SPLINTS

As the manufacture of metal splints now forms one of the principal occupations at which disabled men are engaged, in the curative workshops attached to the orthopædic hospitals, it is proposed to describe here those simple types of splints for which experience has shown the greatest demand exists. Exact measurements are given of each type, together with a description of special appliances designed to facilitate their manufacture.

They are from the designs, and conform to the basic principles laid down by Major-General Sir Robert Jones, which are :

A. Simplicity of design.
B. The preservation of physiological rest with immobility of the limb.
C. Ample access to the wounded portion of the limb.
D. Fewness of types.
E. Cheapness of production.
F. Ease of cleansing.

A. Simplicity of design—not only permits of ease of manufacture by unskilled workers, but ensures that the surgeon at once grasps the mechanical principle of the appliance, and has not to lose valuable time investigating clever mechanical movements.

No adjusting mechanisms should be used. Alterations may be effected by bending. To this end the material employed is of such a strength that, while due regard is paid to rigidity, the surgeon may alter the splint at the bedside, without special appliances.

Screws and bolts, if used, should only be those obtainable ready made.

Turnbuckles and long screws as used in the old types of MacIntyre splint are costly to make. Universal adjustments to make a splint fit any shape or size of limb rarely fulfil their object. This is obtained more rapidly and cheaply by having splints made in two or three standard sizes.

It is an advantage that all splints be made suitable for application to either side of the body. This applies particularly to those made in quantity, and intended for distribution. In orthopædic hospitals supplied with workshops, special cases may be dealt with as they arise.

B. Rest to a wounded limb can only be secured by the splint being rigid. The main iron which connects the different parts must be sufficient cross-section to ensure this. The plates of metal by which the splint is

bound to the limb must be of ample width and proper curvature. The workman should model them to his own limbs.

C. Access to the wound is ensured by the splint not embracing the whole limb, and by the gap which is formed in the splint, as in the case of the elbow, being of sufficient size that the surgeon may pass his hand or bandages between the limb and the iron bar joining the upper and lower portions of the appliance.

In the case of splints made only of rod iron, e.g. the various types of Thomas splint, the rods must stand out sufficiently far from the limb to allow of bandages and dressing pads being placed between them and the limb.

D and *E*. Fewness of types and cheapness—not only makes for greater ease of production in quantity but prevents the accumulation of appliances in hospital stores not in general demand.

As the majority of the pieces of sheet-metal used in splint-making are of small size, waste material of all kinds can be pressed into use.

F. Iron splints have the advantage over those of other material that they do not absorb the discharges from a wound, and when soiled may be cleansed by fire, repainted if circumstances permit, restored to their original shape, repadded, and used over and over again without any fear of their carrying infection from patient to patient.

In general, splints for the arm should be of the lightest possible construction. The patient has to bear all the weight of the appliance under certain circumstances, as it is attached to his neck and shoulders. He is able to a slight degree to control the movements of the injured limb. In the case of the leg, weight is not to be considered, except in so far as it affects the transport of splints in bulk. Here the splint is supported in the bed or slung from overhead. It has to carry the great weight of the leg between two bars which are only joined at their extremities. Sagging or springiness of these bars will take place if metal of insufficient thickness is used. The patient is unable himself to prevent movement either of the limb or the appliance, and the least jar causes pain.

Cross-pieces of metal, bridging under or over the leg in such splints, while ensuring the rigidity which is so essential, interfere with the dressing of the limb, or the placing of trays in the bed beneath a wound.

However roughly and rapidly a splint may be put together, it ought never to leave the workshop with any sharp or jagged edges. A few minutes with the file and emery cloth will remove all sharpness, and prevent damage to those using them. Sheet-metal which forms the channel-like supports for the limbs ought to be belled outwards at both upper and lower ends, as the slight movement of the patient in the splint always uncovers that portion of the metal first, if the padding is not well secured.

Further, the belling or turning out the edge of the metal gives a grip to the padding and bandages on the outer side of the splint.

If time permits, all splints should be painted, but, if only an hour or two can elapse before the splint is required, a coating of shellac varnish (French polish), applied with a brush, will keep the iron free from rust, and will dry rapidly.

Having collected the necessary tools, these are distributed in the work-rooms in the most suitable positions for a regular sequence of work, from the reception and cutting up of the raw material to the final painting, storing, and packing.

The average bench space allotted to one man is six feet.

The cutting up of the raw material is done as soon as possible after its arrival in the workrooms by lever bench-shears. This at once reduces its bulk, allows the sharp clippings to be removed, and the cut-out portions to be easily stored. Next, the pieces are cleaned and filed by hand, or, if very rusty or dirty, are transferred to a 'Rumbler' machine, which cleans them mechanically. By either process, or a combination of the two, the edges of the metal are rendered smooth and safe to handle. The positions of the holes are marked and bored, the iron is bent into shape by hammering on rounded anvils, or rolling it through a tinman's rolls, a special machine like a mangle, or in jigs or appliances each designed for one particular purpose. The various component parts of the splints are then assembled, and the completed article sent to the painting room.

It devolves on the superintendent or manager of the shops, before productive work can be undertaken, to construct patterns or templates, which the workers will copy.

These are prepared in metal exactly similar to that used in the finished article. They are all painted a distinctive colour and lettered to indicate their ultimate position. A completed pattern splint is coloured in a similar way, and also lettered so that the workers have both patterns to guide them, viz. the unassembled and assembled parts.

Where a splint is made in three sizes, as in the case of the elbow, all the small size patterns are coloured blue, the middle size green, and the large size red.

All bars of iron are cut in length to wooden pattern bars on which the site of all holes to be bored are marked. The jigs or appliances for bending these to a uniform curve are constructed as described later, and fixed to the benches.

Once the principle of any of these jigs is grasped it is easy to construct similar machines of wood or iron to meet various requirements.

Cleaning the iron and removing the sharp edges left by shearing constitutes one of the most tedious parts of the work, and where old iron is used this trouble is accentuated.

Cleaning may be effected by fire in the case of paint and grease; the plates are made barely red hot, and while held in a pincers are brushed with a steel brush.

Emery cloth may be used, but is slow, costly, and very trying on the fingers. Rumbling is the best method, and will remove not only rust and the black scale on new iron as it comes from the makers, but at the same time rounds the sharp edges left by the shears. It leaves the whole surface bright. The presence of rust and dirt prevents paint adhering properly.

If no machinery for rumbling is available recourse may be had to filing or grinding on an emery stone.

Emery-wheel grinding, while rapid, leaves sharp edges, requiring further handwork. It is more suited to removing larger masses of metal from the ends of heavy bars. It causes metal and emery dust to fly in the air, with great risk to the workers' eyes and lungs, and if possible exhaust fans ought to be fitted to such machines to obviate this risk.

The fitting and mounting of emery wheels ought to be carried out by men thoroughly versed in this work, as an improperly mounted wheel, or one driven at an incorrect speed, may cause serious accidents through bursting of the wheel.

The Rumbler Machine.

This consists of a large octagonal steel-lined barrel, which has short axles attached to either end. The axle must not traverse the inside of the barrel. It is made to revolve on its axis at from thirty to forty revolutions per minute.

A portion of one of its eight sides is made to hinge open like a door, and screw clamps allow of this being firmly closed. This door should be perforated with quarter-inch holes to allow of the escape of dust and dirt, which hinders the action of the machine. On one end of the octagon a wooden pulley wheel is built up of wood blocks, of sufficient size that when these are turned true a pulley wheel of large diameter is formed, by which it is driven.

The objects of iron to be cleaned are placed in the machine, and small bits of scrap iron, old nails, &c., may be added as a scouring medium. In action the loose metal objects are pounded against one another, and in from two to four hours will be found bright and clean.

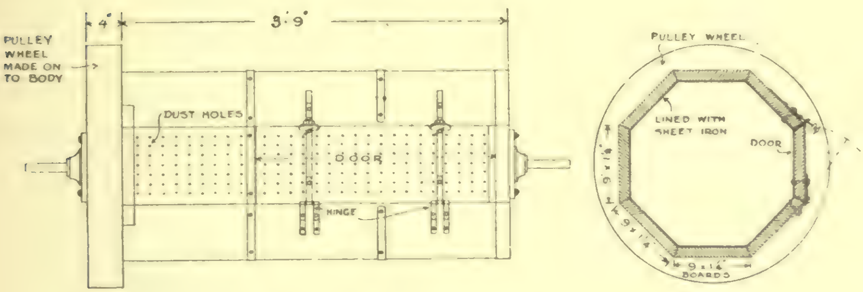
Rumblers differ in their action according to their size, and the nature of their contents. In use they create a great deal of noise and dust, so must be installed outside the workrooms, and be actuated by belts and shafting carried outside the building.

In the splints which have sheet-metal riveted on to bars, all the holes are bored in the bars after these are bent, otherwise the bar would give

way at the hole during bending; but the marks for the holes are put on while the bar is still straight.

The flat sheet-metal plates have at first one hole only bored in them. Its position should be shown in the pattern, and in each case this single hole is placed one inch from the edge of the plate nearest to the joint of the patient, as knee, elbow, or wrist. The plate is riveted by this hole into position on the main bar, and the second rivet hole subsequently bored, and a rivet closed in it. This ensures (1) that the correct end of the tapered plate is placed in proper position; (2) that the correct distance

RUMBLER



ELEVATION. SECTION

Fig. 181.

is maintained between the plates on the splint to allow of the gaps at the knee, elbow, or wrist being of the proper dimensions.

The splints being finished should be taken at once to be painted to avoid rusting, and any oil or grease removed from them before the paint is applied.

Machinery and Tools required.

Patterns.
Benches and vices.
Shears, lever.
Shears, hand.
Anvils of special type.
Tinman's rolls.
Wooden mallets.
Hammers, round pane, for riveting.
Files.
Emery cloth.
Drilling machines or lathe with drill attachment.
Oil cans.
Twist drills.

If Power is Available.

Drilling machines.
Twist drill gauge.
Grinding gauge for drills.
Emery or carborundum grinder.
Oil cans.
Lathes.
Grindstones or fans for forges.
Lubricating oil.
Rumbling machine.

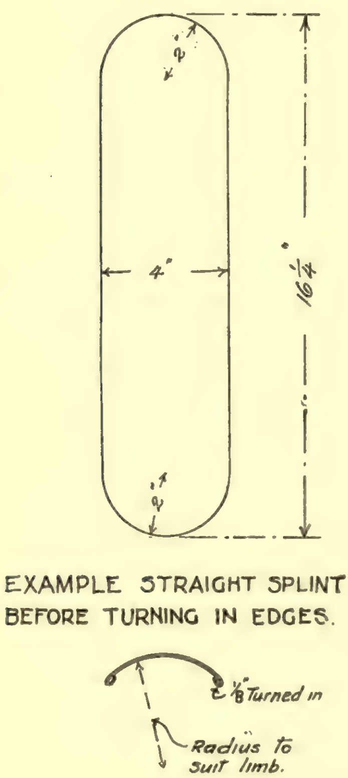
Machinery and Tools required.

Hone for sharpening drills.
Countersinks.
Centre punches.
Hollow punches or ' Dollies '.
Cold chisels.
Bending jigs or tools made for one special purpose.

Forge.

Patterns.
Forge and bellows.
Brazing hearth and bellows or gas blow-pipe and bellows.
Brass wire or spelter and borax for brazing.
Benches and vices.
Anvils.
Anvil chisel.
Hammers.
Tongs.
Bending tools.
Files.
Centre punches.
Cold chisels.

The following are the dimensions of the pattern plates for marking out straight co-aptation splints (Jones) in inches :



Pattern metal to be cut.	Finished length of splints.
$7\frac{1}{4} \times 3$	7
$8\frac{1}{4} \times 3$	8
$9\frac{1}{4} \times 3\frac{1}{4}$	9
$10\frac{1}{4} \times 3\frac{1}{4}$	10
$11\frac{1}{4} \times 3\frac{1}{2}$	11
$12\frac{1}{4} \times 3\frac{1}{2}$	12
$13\frac{1}{4} \times 3\frac{3}{4}$	13
$14\frac{1}{4} \times 3\frac{3}{4}$	14
$15\frac{1}{4} \times 4$	15
$16\frac{1}{4} \times 4$	16
$17\frac{1}{4} \times 4\frac{1}{4}$	17
$18\frac{1}{4} \times 4\frac{1}{4}$	18
$19\frac{1}{4} \times 4\frac{1}{2}$	19
$20\frac{1}{4} \times 4\frac{1}{2}$	20
$21\frac{1}{4} \times 5$	21
$22\frac{1}{4} \times 5$	22
$23\frac{1}{4} \times 5\frac{1}{2}$	23
$24\frac{1}{4} \times 5\frac{1}{2}$	24

FIG. 182.

These splints when cut out in the flat should have their edges folded in all the way round for about one-eighth of an inch. This leaves a very smooth strong edge to the splint. It is rapidly accomplished by hand with the aid of a light wooden mallet, and a 'hatchet stake'. This is a form of anvil shaped like a letter T. It is fixed in a hole in the bench, and has a long sharp upper border. The folding of the rounded ends is done on an anvil made of wood or steel, having a flat circular top whose diameter is somewhat less than the semicircle on the splint about to be finished.

'Cock-up' Palm Splints.

These splints aim at supporting the hand in a position of dorsiflexion without interfering with the movements of the metacarpo-phalangeal joints.

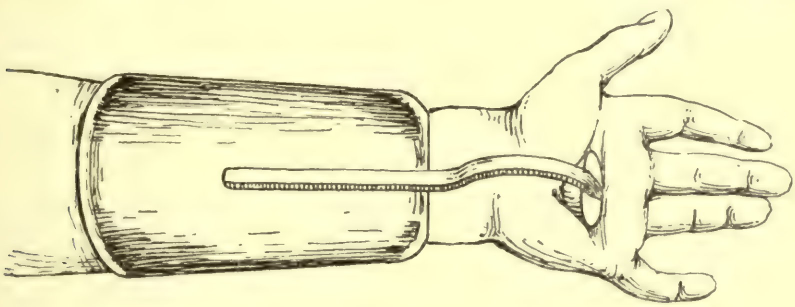


FIG. 183.

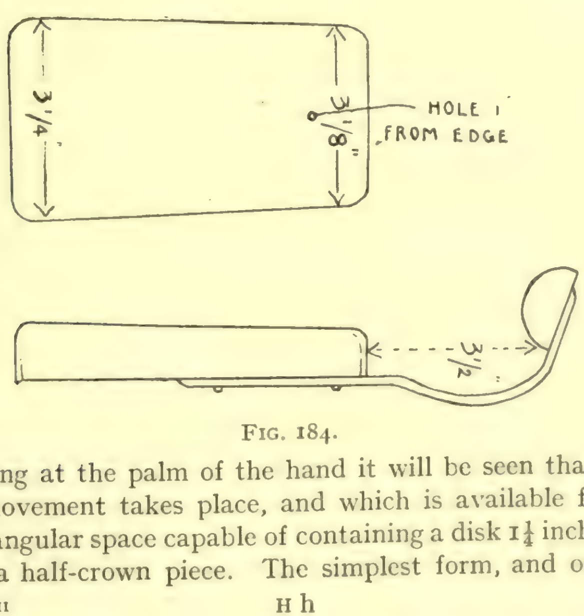


FIG. 184.

On looking at the palm of the hand it will be seen that the area in which no movement takes place, and which is available for the splint end, is a triangular space capable of containing a disk 1¼ inch in diameter, the size of a half-crown piece. The simplest form, and one which can

be made rapidly in large quantities, is a modification of that designed by Mr. G. W. Clyne of Aberdeen.

It consists of a metal rib of $\frac{1}{2} \times \frac{1}{8}$ inch iron, having a forearm piece riveted on to it. The palm support consists of a hemisphere of wood secured to the iron with a screw or rivet, the wooden hemisphere being $1\frac{1}{4}$ inch in diameter.

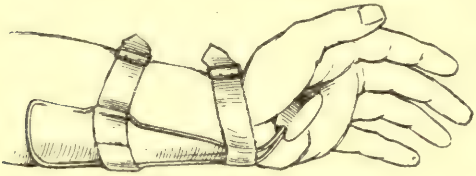


FIG. 185.—Mr. Clyne's splint.

Mr. Clyne's splint is made of two feet of coppered mild steel wire, or 10 to 11 wire gauge, and bent as shown to fit the wrist and arm. The ends being firmly driven into the wood. Straps are provided to fix the splint in position, and the wire is so bent at the points where the straps are sewn on that these cannot get out of place.

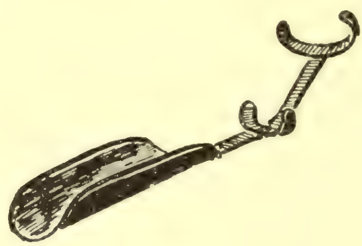


FIG. 186.

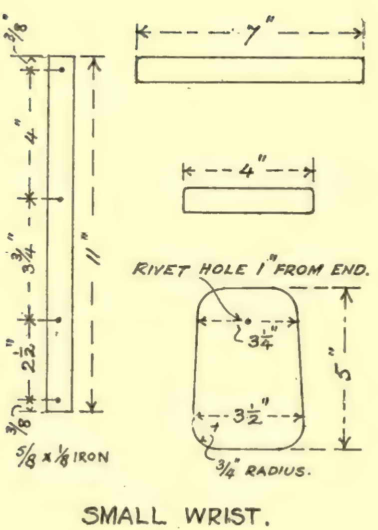


FIG. 187.

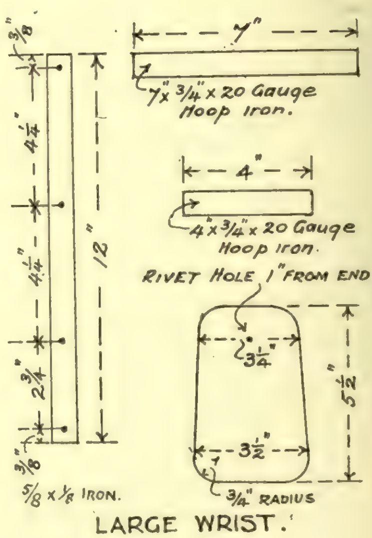


FIG. 188.

Palm splints. Crab or 'cock-up' splint for drop-wrist. Original pattern.

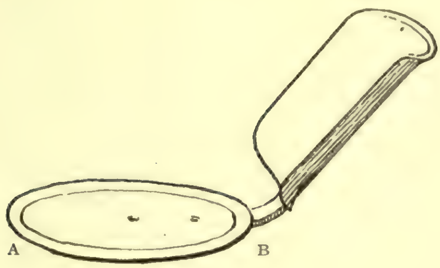
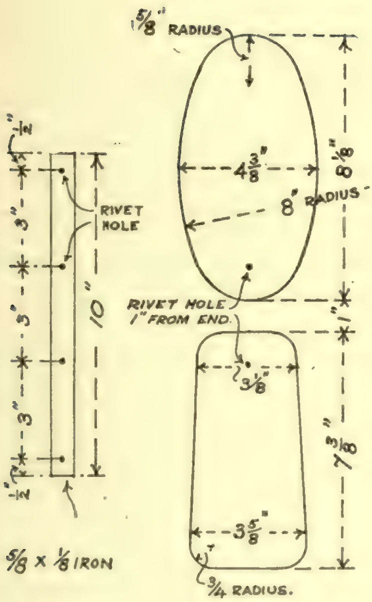
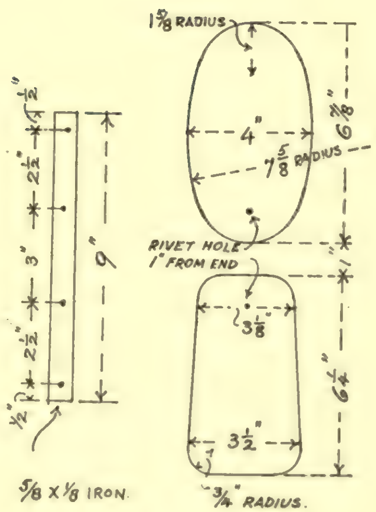


FIG. 189.



LARGE HAND.

FIG. 190.



SMALL HAND.

FIG. 191.

'Cock-up' hand splints. Original pattern for wounds of hand.

(This splint should be so moulded as to convex from A to B.)

Elbow Splints.

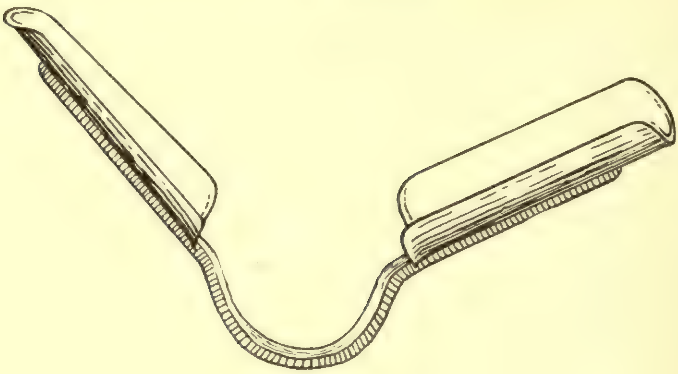


FIG. 192.

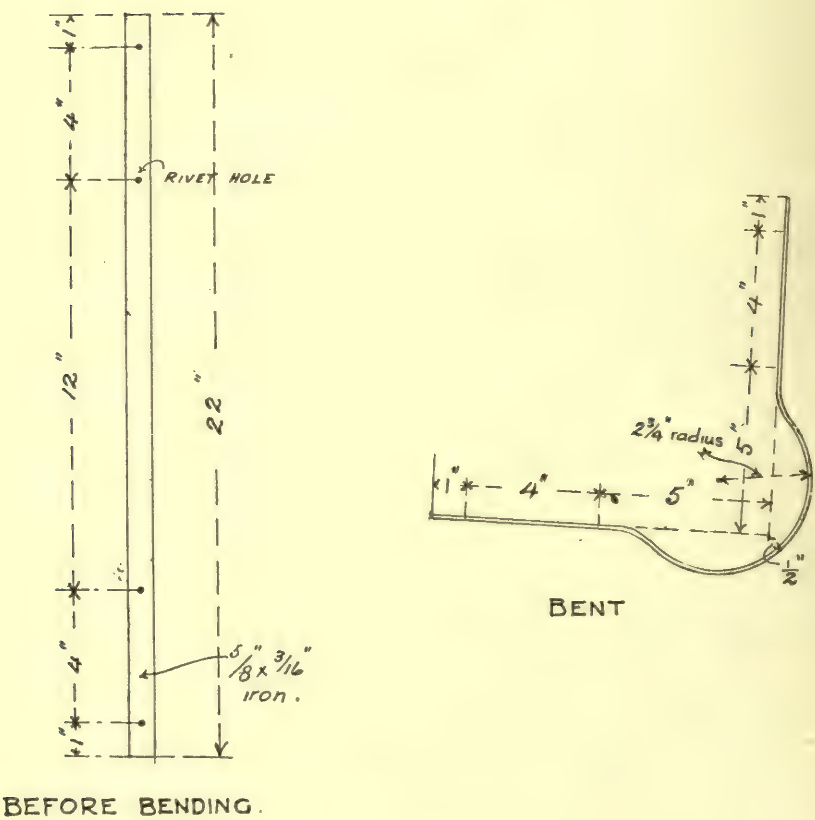


FIG. 193.—Elbow irons, all 3 sizes.

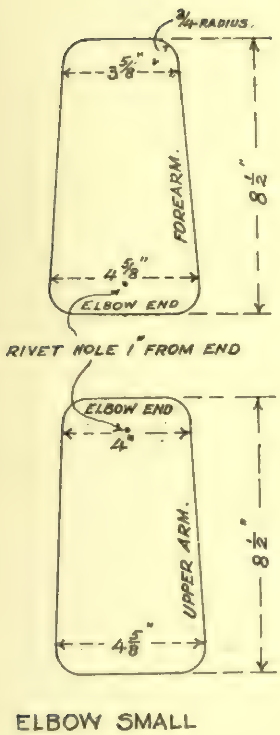


FIG. 194.

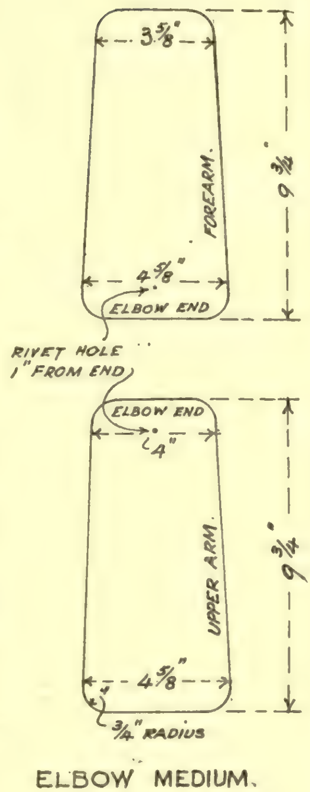


FIG. 195.

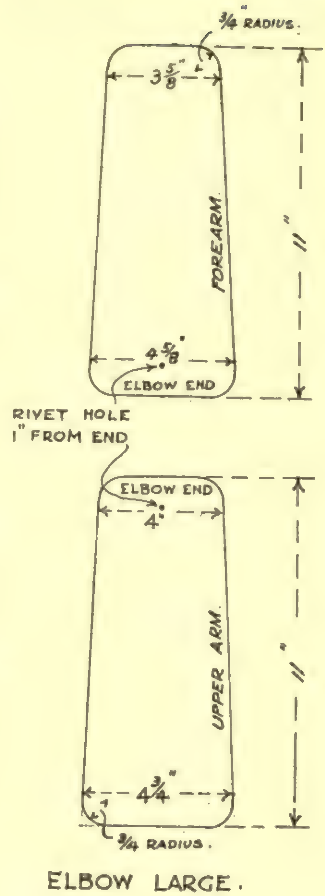


FIG. 196.

Jig for bending Elbow Irons.

A bed-plate of hard wood (A), $\frac{3}{4}$ inch in thickness, and about 15 inches in length by 9 inches wide, is screwed to the bench. A disk of wood $\frac{3}{4}$ inch in thickness by $5\frac{1}{2}$ inches in diameter (C) is screwed to this, and on top of it another disk of wood $\frac{3}{4}$ inch in thickness by $4\frac{7}{8}$ inches in diameter (D) is screwed concentrically.

(B) is apiece of wood $\frac{3}{4}$ inch in thickness, and shaped as shown. It has nearly three-quarters of a circle cut out of it, and is so fixed that an interval or gap $\frac{3}{16}$ inch wide is left between it and the wood block C. Its edge towards E is slightly chamfered, and its two ends FF are rounded.

At E a mark is made to show the central line, and two marks (light

saw cuts) are made from G to G on either side. These are at right angles to one another.

The flat iron rod, which is 22 inches in length, is held with its middle point at E against the block D and bent into a **U** shape (H H). When released it will spring open somewhat, and can now be placed in the groove between C and E. Its two ends are now bent outwards till

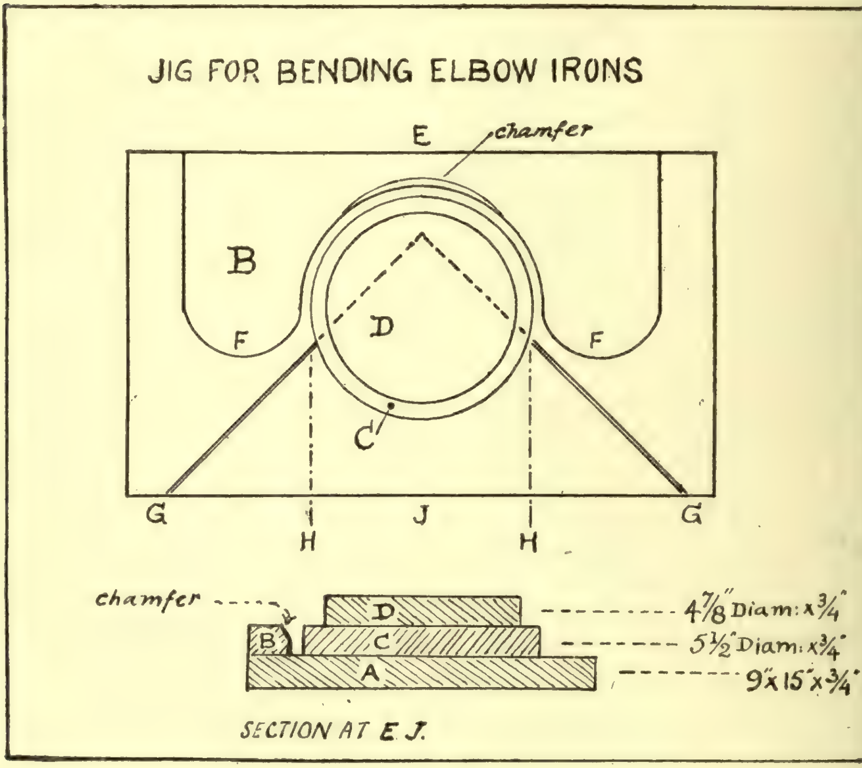


FIG. 197.

they come to rest over the lines GG. The object of the chamfer or cutting away of edge of the wood at E is to facilitate removal of the bent bar.

A wrench, or a key of iron, specially made, may be used to give added leverage to bend the ends of the bar outwards.

Elbow Extension Splint for Humerus.

In the manufacture of this splint $\frac{1}{4}$ inch round iron or steel rod is used throughout, the socket or junction piece (Fig. 204) at the elbow end

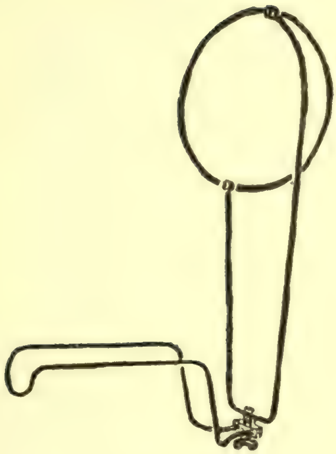


FIG. 198.

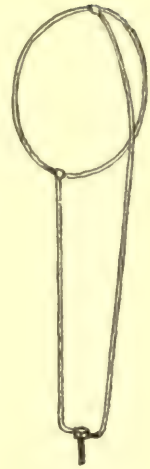


FIG. 199.

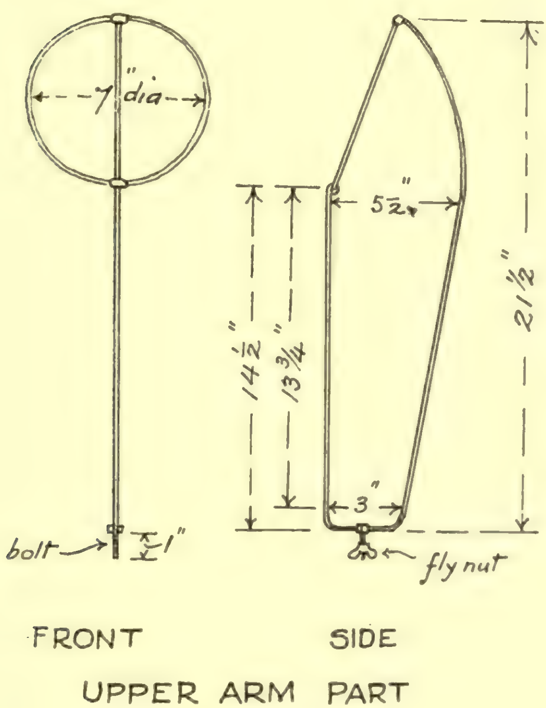


FIG. 200.

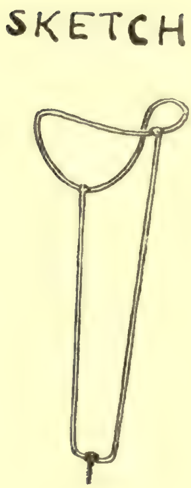


FIG. 201.

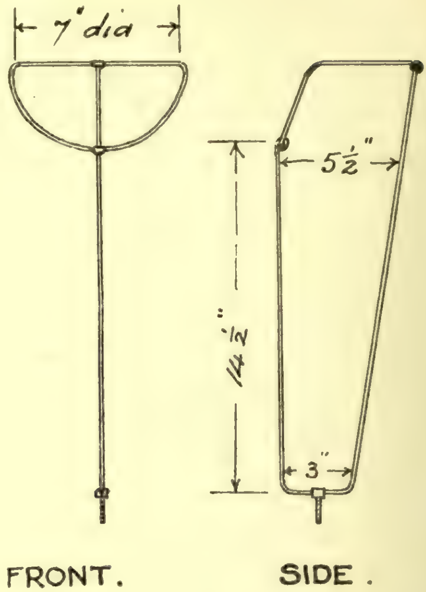


FIG. 202.

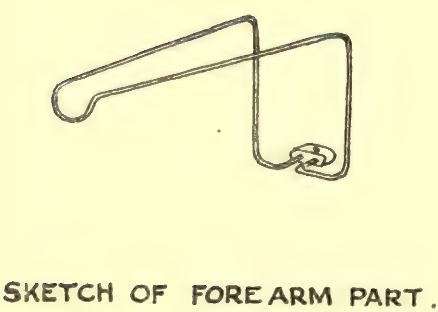


FIG. 203.

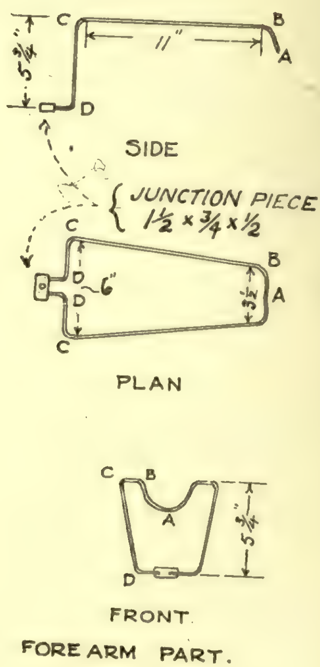


FIG. 204.

of the forearm part being made by cutting lengths of $1\frac{1}{2}$ inch from a bar of iron whose cross-section is three-quarters of an inch by one-half inch. This is bored on its narrow side with two $\frac{1}{4}$-inch holes $1\frac{1}{8}$ inch apart, and on its broad surface a central hole five-sixteenths of an inch in diameter is bored. When the bar of iron forming the forearm piece is bent to shape its free ends are brazed into the two $\frac{1}{4}$-inch holes.

The elbow ends of the rods forming the upper arm part (Fig. 99) are brazed into the head of a hexagon-headed 'set screw' $\frac{5}{16}$ inch in diameter by 1 inch in length, and this screw with its wing nut forms a swivel when set in the central hole in the socket. This permits the upper arm part to be turned round to suit either a right or left arm. This upper arm portion requires only a sheet-metal template or pattern to show lengths and curvatures. An alternative design for the upper arm part is shown in Figs. 201 and 202. In this the ring for the shoulder is bent on itself nearly to a right angle.

The forearm portion, Figs. 203 and 204, requires two separate jigs—to bend the rod uniformly. It will require from 42 to 50 inches of rod to make this portion, depending on the size of splint required. The jig (Fig. 206) only shows the arrangement for one size, for clearness.

Holding the first jig (Fig. 205) in the vice, the rod is bent at its middle into a U curve round the semicircle of iron E. Its ends come under the cross bars of iron F. By lifting the ends vertically upwards the wrist curve at A is in Fig. 204 produced. The second jig (Fig. 206) is now used, held in the vice. It has a channel formed at one end, and at the other two pairs of holes are bored to easily admit an iron staple (U-shaped).

The rod is laid in the channel. It is pinned down to the jig by the staple, placed as close as possible to the wrist-bend formed in the last operation at the point G, and the portion of rod projecting beyond the channel can now be bent to a right angle sideways to produce the bend C in Fig. 204. A similar procedure with the staple placed in the pair of holes nearest to the channel produces the bend D in Fig. 204.

The last out-turning of the ends may be done by bending in the vice. This principle of jig-making may be elaborated for any curve or bend, and it automatically controls the length of the straight portions of the rod between each bend.

For different sizes of splint it is only necessary to bore additional pairs of holes in the second jig at appropriate distances from the outer end of the channel.

Straight Thomas Splint for Arm.

This splint is made in the same way as a Thomas leg-splint, both as regards the junction of the metal bars to the shoulder-ring, and the

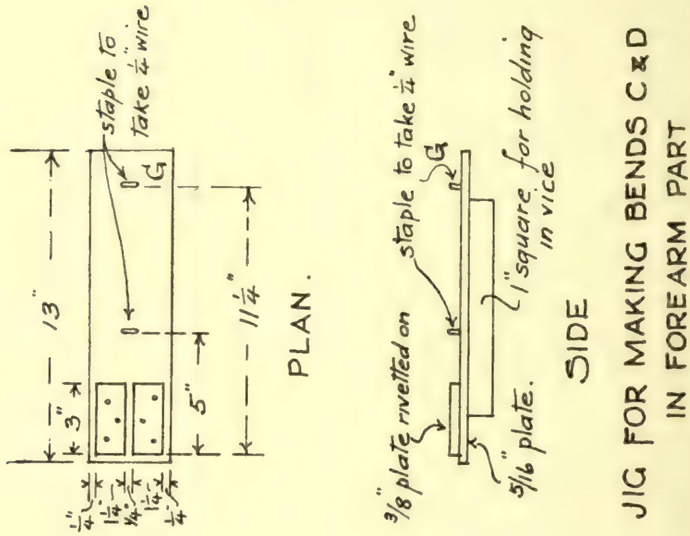


FIG. 206.

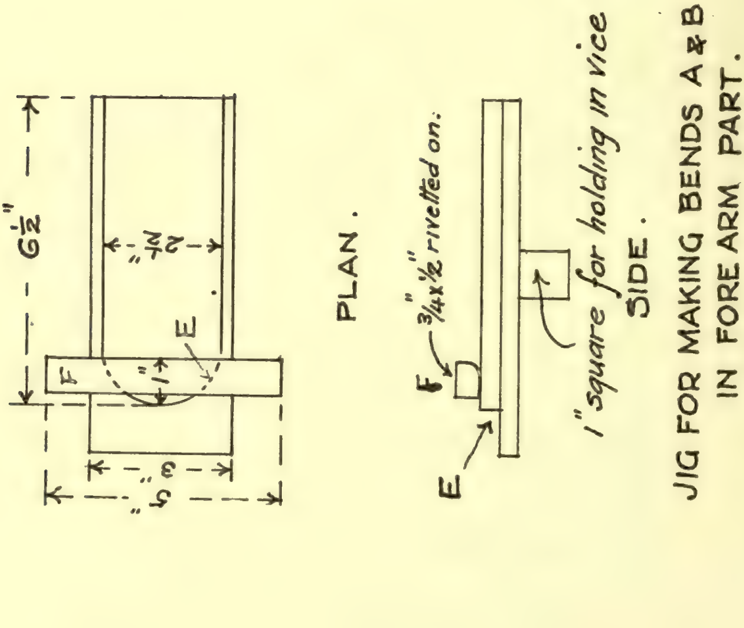


FIG. 205.

production of the **M** curve at the hand end, which methods are described later under Thomas's leg-splint. It is constructed throughout of a $\frac{1}{4}$-inch round rod. It has gone through various modifications as regards the ring or loop, the chief ones being to allow this loop to swivel, that the injured arm may be brought down to the patient's side.

In the original type a 6-inch ring was placed at right angles to the shanks as at A, Fig. 207, the wrist end being 3 inches wide. Depending on the lightness of the metal, the shanks may both be bent close to the ring to set this at an angle, as at B, Fig. 207.

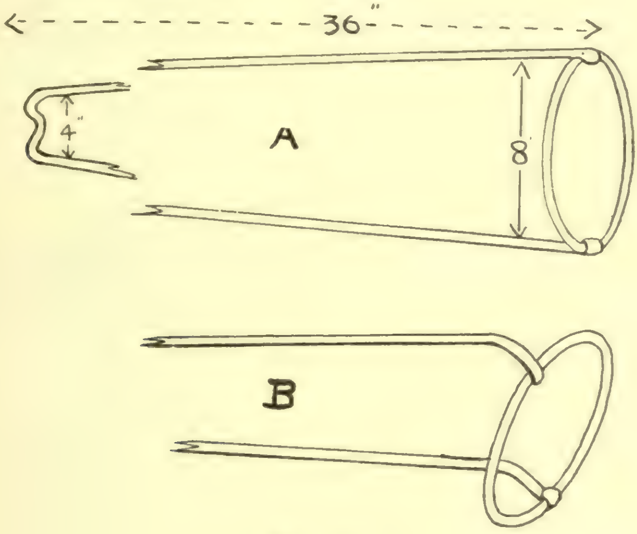


FIG. 207.

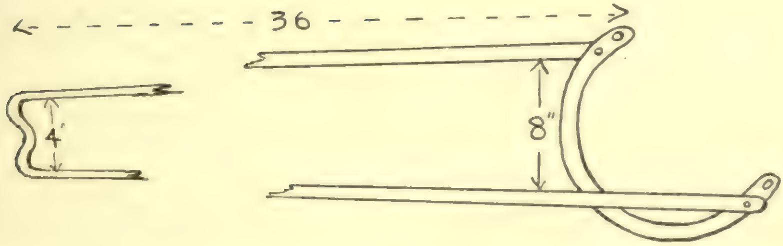


FIG 208.

The chief modification of this splint is one in which the shoulder-ring is replaced by a semicircular loop of iron loosely riveted on to the flattened ends of the rods, as shown in Fig. 208.

The semicircle is made of 13 inches of flat iron, half an inch wide by one-eighth of an inch in thickness. The rivets on which it swivels are one inch from the end of the bar, and at the projecting ends of the loop are two large holes. These can be used either for suspension, or for

attachments of padding, and adjustment. Should the surgeon desire a flexible pad in the axilla, the semicircle of iron can be thrown to the outside of the shoulder, and a soft padded strap, attached to the two holes in the end of the semicircular iron, may be placed in the armpit.

Skeleton Leg-splints.

These are made in three sizes, the toe and heel pieces and the heel curve being the same for all sizes.

The jig for bending the heel curve in the main bar is made of hard wood, and does for all three sizes. It will be seen by reference to the measurements of the splints that the part of the metal placed beneath

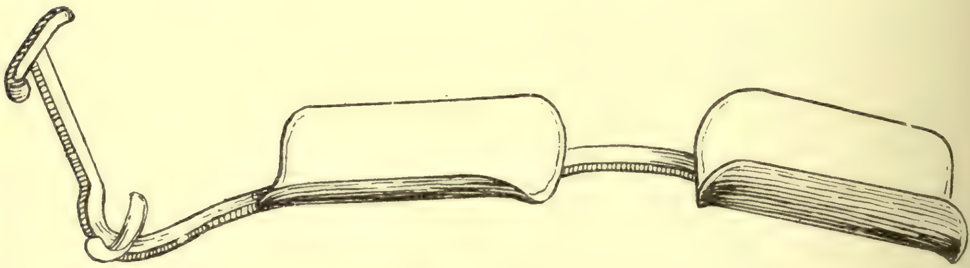


FIG. 209.

the sole of the foot is three-quarters of an inch longer in the middle size than in the small size, and the large size is three-quarters of an inch longer again.

A base plate of hard wood (Fig. 214) three-quarters of an inch in thickness, and 20 inches in length by 9 inches in width, is screwed to the bench. On it are fastened pieces of wood three-quarters of an inch in thickness by 2 inches wide, and shaped as shown in Fig. 214, A, B, C, D, E. They are spaced so that between each is a groove three-sixteenths of an inch wide. A block of wood (G) acts as a stop at the ends of the grooves between A, B, C, D.

The groove between A and B is the shortest for bending the small size of iron, that between B and C for the middle size, and that between C and D for the large size, the difference in the length of the grooves being three-quarters of an inch in each case.

From the mouth of each groove a mark (a slight saw cut) is made in the base plate at an angle of 135° F, F, F. It is to one of these guide-marks that the iron is bent, after its end has been pushed home into the groove suited to the size of the splint for which it is intended.

On the block of wood D are three marks 1, 2, 3, three-quarters of an inch apart, and corresponding in their distance from the curved portion of the block D to the length of the other grooves.

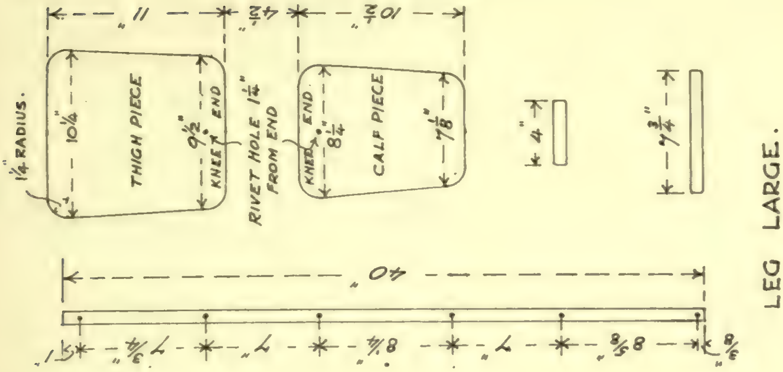


FIG. 212.

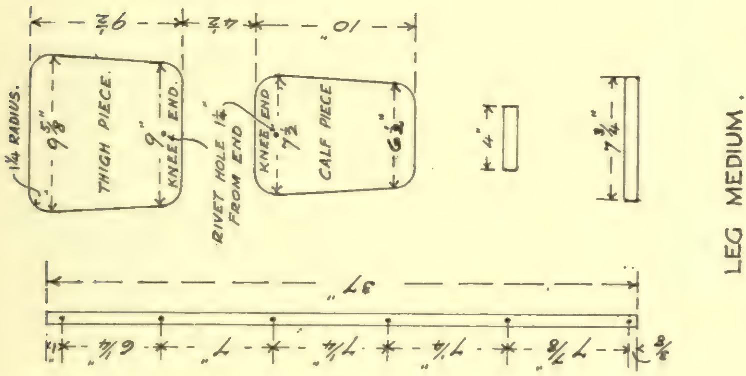


FIG. 211.

Skeleton leg-splint measurements.

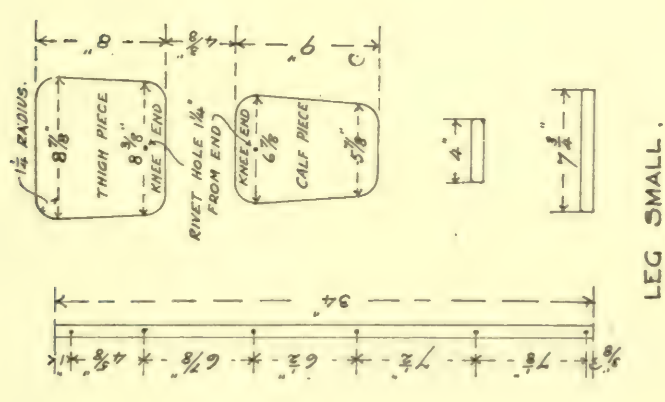
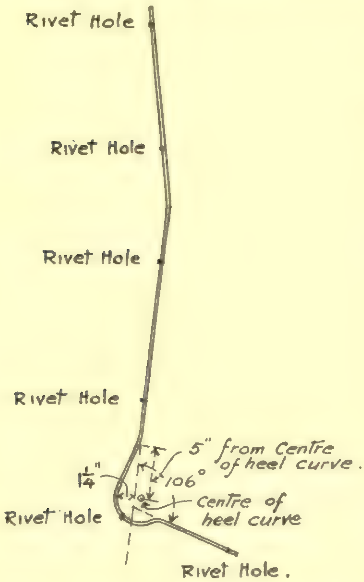


FIG. 210.

A circular piece of wood H, three-quarters of an inch in thickness by $3\frac{1}{2}$ inches in diameter, is fixed to the base plate as shown abutting against E, and leaving a gap three-sixteenths of an inch in width between the nearest point of D to H.



LARGE LEG IRON BENT TO SHAPE.

FIG. 213.

A hole to take the iron peg or key three-eighths of an inch in diameter is bored at J, 5 inches from the centre of the block H, and guide-lines K, L are marked on the base plate as shown. The angles of these lines are made to correspond to the angles given in Fig. 213, showing a large leg-iron bent to shape; the foot-piece of the splint being at an angle to the calf-piece of a little over a right angle.

For example, if it is required to bend the main iron for a large size skeleton splint, the bar, 40 inches in length, is pushed into the groove between C and D, and bent to the left till it comes to rest at the mark F. It is now withdrawn and laid in the groove between D and E, allowing its end in the groove to lie opposite the mark 3. It is now bent to

JIG FOR BENDING LEG IRONS.

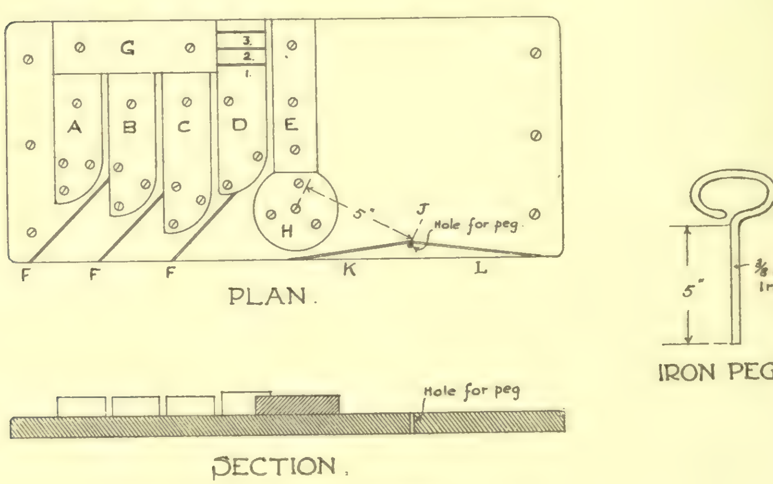


FIG. 214.

the right, round H, until it comes to rest on the mark K. The iron peg is now inserted into the hole J, and it is bent backwards round the peg towards the workman till it comes to rest over the mark L.

The bend behind the knee is formed by hand after the splint is finished.

Splint for Drop-foot.

This is made similar in shape to the rectangular foot-splint described by Major-General Sir Robert Jones for use in treating injuries of the

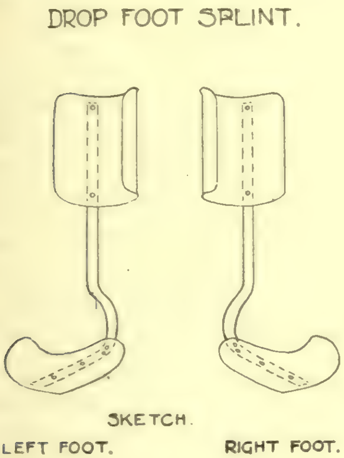


FIG. 215.

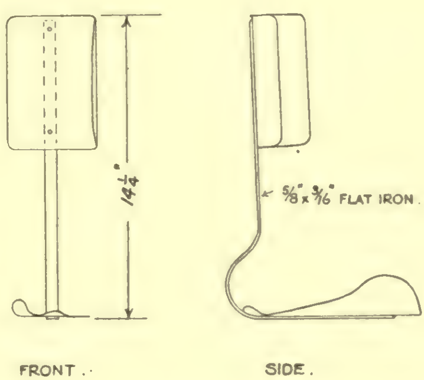
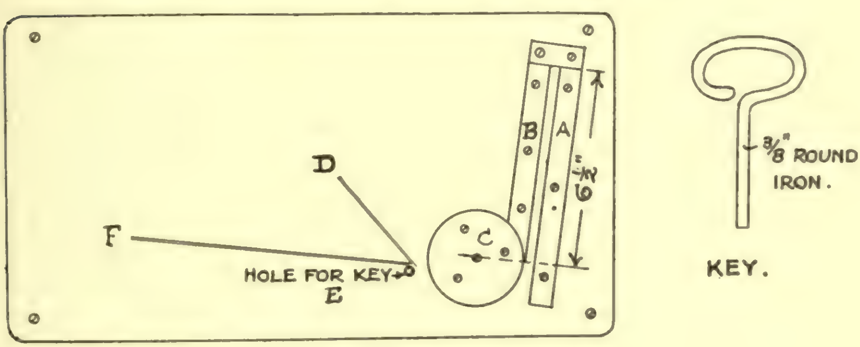


FIG. 216.



JIG FOR BENDING IRON.
LENGTH OF IRON BEFORE BENDING 21½".

FIG. 217.

ankle-joint. The pattern serves for either right or left foot. When intended for cases of paralysis of the foot the calf-piece of the splint is so set on the main iron that it bears more on the outer portion of

the calf. The measurements shown in the drawing are those of a medium-splint. In other sizes only the sole-piece need be altered to match the length of the foot.

The jig for bending the iron bars (Fig. 217) is made of wood, and is similar to those described for bending elbow and knee irons. The iron bar is placed in a groove between two blocks of wood (A, B) secured to a base plate of timber. It is bent round the circle of wood C till it comes to rest at the mark D. An iron key or pin is then placed in the hole E, and the iron bent round it till it comes to rest at the mark F.

Thomas's Leg-splint.

This splint is constructed of $\frac{3}{8}$-inch round iron or steel bar. At its upper end it has an oval ring of $\frac{5}{16}$-inch iron attached at an angle to the two side bars, and its lower end is formed like the letter **M**. As the splint is used for a self-contained extension mechanism, its length measured on the shorter or inner straight rod must be from five to six inches longer than the patient's leg measured from the perineum to the heel.

The outer rod A is four inches longer than the inner one B, and these two arms are formed by bending a rod about 86 inches in length at a point 4 inches to one side of its centre into a **U** curve. By the plan described further on, these arms are recurved on themselves, making an **M**-shaped bend, the indent of the **M** being about one inch in depth ; the hip-ring being formed by bending a bar of $\frac{5}{16}$-inch rod iron of suitable length into an oval shape.

The sizes of the rings vary from those obtained by bending bars of 22 inches in length which will form an oval $7\frac{1}{2}$ inches by $6\frac{1}{4}$ inches, suitable for a very small thigh, to those obtained by bending a bar $30\frac{1}{2}$ inches in length to form an oval 10 inches by 9 inches. In each case the narrow end of the oval is on the outside or longer portion of the splint. The padding placed on these rings is quite circular in section, and is $1\frac{1}{4}$ inch in thickness on the inside (short arm), diminishing equally to about three-quarters of an inch at the outside. This must be remembered when measuring a patient, as the iron occupies a position in the middle of the padding. A rough rule for finding the length of iron required for a special case is to take the circumference of the thigh horizontally at the level of the perineum, and add four inches to it.

The angle at which the thigh-ring stands to the inner arm of the splint also varies with individual requirements, that angle obtained by making one arm four inches longer than the other being about 55°. If anything the angle ought to be less than this rather than greater, and if the surgeon at the bedside should find the angle too great, i.e. the outer part of the ring inclined to press on the anterior superior spinous process of the

ileum, he can reduce it by bending the outer long arm of the splint forcibly outwards at the point A, Fig. 218.

This is best done by placing the splint on the floor, as in Fig. 219, and placing the foot at the point A and grasping the short arm at both B and C, lifting C gently, but through a greater arc than B.

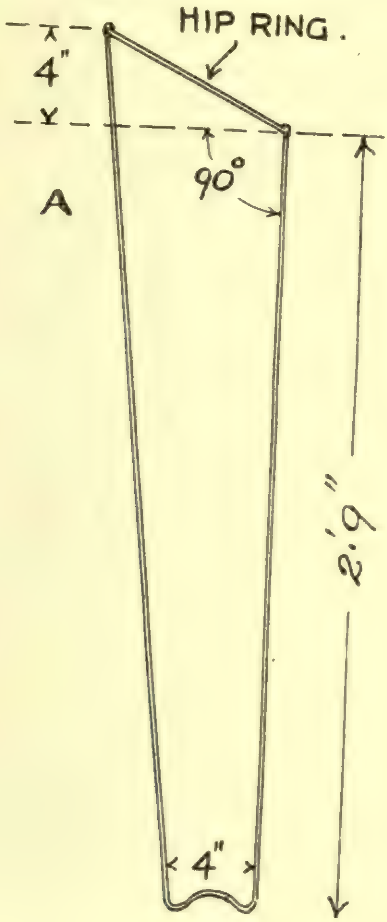


FIG. 218.

The M-shaped bend at the lower end of the splint must be made with the rod heated at that point to a dull red.

One method of making this curve is to have a block of metal held in the vice in which three stout steel pins are placed as in Fig. 220.

A U-shaped loop is first made round one of the outer pins A or C at the point corresponding to the centre point of the M curve. This loop is now placed over the central pin B with the rods away from the worker, and they are then bent back towards him round A and C.

Another plan is to have a special clamp, which sits in the vice as in Figs. 221, 222. The iron rod is heated and laid between the jaws of this, and the vice screwed upon it. It forces the hot bar of metal rapidly into the desired shape.

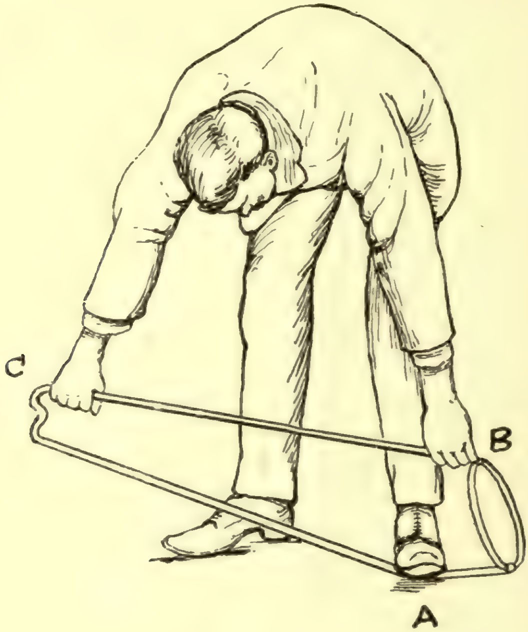


FIG. 219.

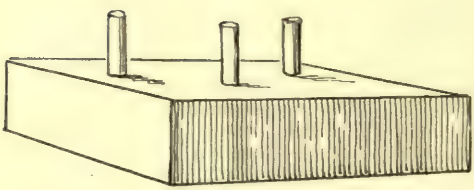


FIG. 220.

Three methods can be adopted to join the iron rings and fix them on to the long bars. These are :

1. Common welding.
2. Oxyacetylene welding.
3. Brazing.

Common welding of small iron by the hammer requires exceptional skill. Special fuel must be used, and the forge fire not contaminated by other classes of work being heated in it, such as brazing jobs.

Oxyacetylene welding requires a special plant. It consists of fusing the iron objects together, and melting into the joints drops of iron of a special quality. Intense heat is generated by the flame of a blow-pipe supplied with acetylene gas and oxygen. The apparatus needs care in its working to prevent accidents from the highly explosive and poisonous nature of the gas, and the workers' eyes must be protected by blue

CAST IRON JIG FOR MAKING M BEND AT BOTTOM OF THOMAS' SPLINT.

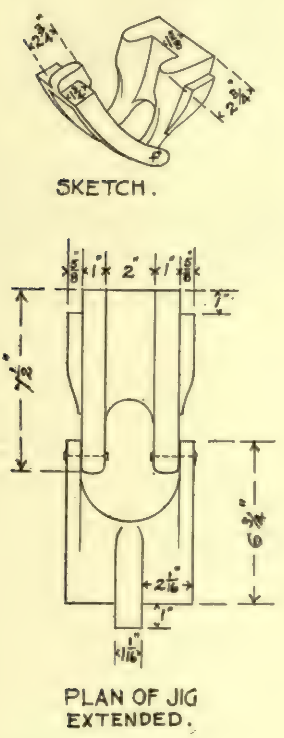


FIG. 221.

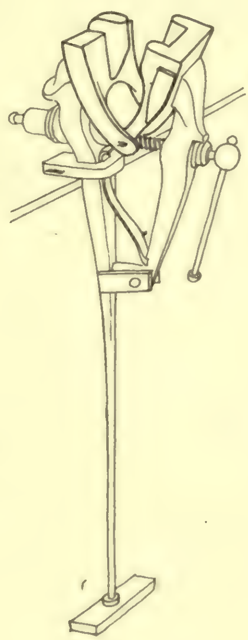


FIG. 222.

spectacles from the dazzling light. Otherwise the technique can be quickly learnt, and its range of utility in effecting repairs to general ironwork far exceeds any other method.

Brazing, although slower in the execution of work than either of the preceding methods, has the advantage that it can be readily taught, and it is used in so many different kinds of metal work that few orthopædic hospital workshops would be found without some mechanic possessing the necessary knowledge.

To get the necessary heat, two methods are in use :

1. A brazing-hearth and bellows, identical with a forge, and using coal or coke as fuel.
2. A gas blow-pipe and bellows, and hearth.

This procedure as applied to splint-work is here shown. Nos. 1, 2, and 3 of Fig. 223 represent the stages in preparing the end of a bar of round iron so that it will grip the ring of iron forming the thigh end of

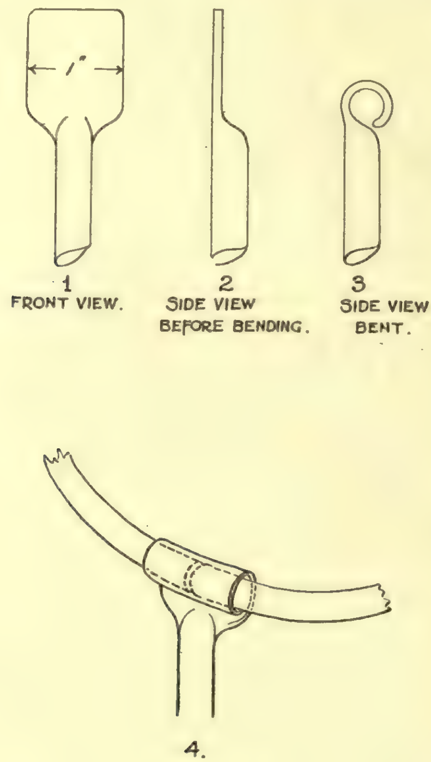


FIG. 223.

a Thomas splint. This is done hot on the anvil. Both bars of the splint are so prepared and clenched on the ring, the joint of the ring itself being enclosed in the loop of one or other rod, as in No. 4, Fig. 223. A joint so formed is placed in the fire, the heat is localized by the adjustment of small pieces of fuel, and the blast of either bellows or gas blow-pipe carefully directed on to it. When nearly red-hot, powdered borax is thrown on the work to dissolve the coating of oxide formed on the iron. Brass rod or wire is melted into the joint. The brass will flow at a bright red heat, combine with the iron, and fill the crevices of the metal, and render the whole solid.

An aid to the construction of the rings is to have heavy oval blocks of wood carved to the correct curve, or similar shapes made of cast iron on to which the rings can be shaped. An iron casting (Fig. 224), having

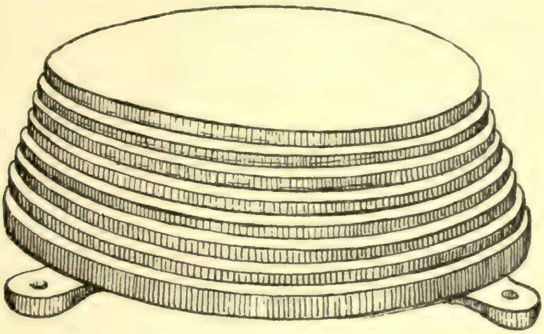


FIG. 224.

several different-sized ovals on it superimposed, has been devised for this purpose. Each oval differs in girth by about one inch—the resulting difference in diameter being about five-sixteenths of an inch.

ELECTRICAL DEPARTMENT

BY

MAJOR W. ROWLEY BRISTOW

ELECTRICAL DEPARTMENT

SCOPE OF THE WORK

An Electric Department is an essential part of an Orthopædic Hospital, since electrical treatment has been recognized during the war by surgeons generally, as an essential part of both pre- and post-operative care of many conditions. It must be borne in mind that we are here considering the uses of electrical treatment from the point of view of orthopædic surgery. There are many therapeutic uses of electrical treatment which properly belong to other branches of surgery and to medicine with which we are not concerned here.

But electrical treatment is not a panacea, and has well-defined limitations. If any and every type of case is sent to the department for treatment, the results will be disappointing. The cases require selection by a surgeon who understands both the merits and limitations that this method has to offer.

Again, the particular merits of electrical, as opposed to bath or massage treatment, must be considered, since it is not possible for each individual patient, when the numbers are large, to have each and every form of physio-therapeutic treatment.

The whole subject of physical treatment must be looked at broadly. The various forms, baths, electricity, massage, remedial exercises, and gymnastics, cannot be separated into water-tight compartments. They must overlap, and for several ailments it is not possible to say which is the best form to select.

In the present chapter the work performed in the electrical department at one big centre will be described together with the details of its application, and an enumeration of those conditions in which it has proved of benefit to the patient.

The writer is most anxious that this form of treatment should be put on a rational basis, stripped of its mysteries, and presented in such a way that it can be understood by surgeons generally.

Among the conditions requiring electrical treatment may be noted:

1. **Peripheral Nerve Injuries.** Complete or incomplete division—in the non-operative, pre-operative, and post-operative stages.

2. **Muscle Atrophy.** Especially is this true when one member of a muscle group is wasted out of proportion to the remainder, as is commonly seen after injuries to the knee-joint, when the vastus internus suffers most.

Again, when a joint injury or a fracture necessitates complete fixation of the limb, the muscles may be exercised by electrical stimulation, without producing any movement of the joint, thereby lessening the degree of atrophy, maintaining the muscle substance and preventing fibrosis. Much can be done in this connexion in cases of fracture of the femur when union is commencing, and before voluntary movement can be allowed to the limb.

3. **The stiffness following sprains and allied injuries** can in the main be prevented by faradic stimulation of the muscles. The stimulation must not cause pain, and does not do so if carefully carried out.

For the stiff hands and fingers, complicating a combined nerve and arterial lesion, electrical treatment alone is not of much service. Ionization, e.g., will not overcome the stiffness of the metacarpo-phalangeal joints, following sepsis or prolonged fixation in such cases. For these continuous stretching by splintage, coupled with short intervals of massage under hot water, is needed in addition.

Ionization is of considerable service in bringing about improvement in the nutrition of the affected limb, through its action on the capillary circulation. Again, for stiff knee-joints of long standing—due to quadriceps fibrosis following a septic compound fracture of the femur—the electrical stimulation of the quadriceps is only one small part of the treatment. Voluntary effort, combined with various mechanical devices, is necessary to achieve a good result.

4. **Scar Tissue.** Ionization will aid in loosening superficial scars, as will massage. These measures have little or no effect on deep adherent scars.

5. **Functional Disabilities.** In some hands the faradic current is of great service. Electricity is the means to an end. It may prove to the patient that movement of a joint is possible by the working of his own muscles. It prepares the ground for the psycho-therapy, which is the real curative agent.

For these conditions high frequency currents or painful faradic currents are mostly used.

Functional aphonia and allied conditions are said to yield, as a rule, to high frequency treatment, but the results of electrical stimulation have proved disappointing for the aphonia due to shell shock, whereas ‘ suggestion ’ treatment without electricity usually cures.

6. **Trench Feet, Neuritis, &c.** Ionization, and in some hands diathermy, are of service—combined with rest for the affected part. The virtue of electrical treatment in these conditions lies mainly in its power of producing heat. Following a severe neuritis, when the nerve is no longer inflamed and tender, faradic stimulation is called for, whilst in the acute stages it would be disastrous.

7. **Electro-diagnosis—Nerve Muscle Testing.** This is dealt with in another section (p. 63). It should be regarded as part of diagnosis—' The electrical examination is the indispensable adjunct to the clinical examination.'

THE APPARATUS

Current Supply. A direct or continuous current supply is essential. If the supply from the main is alternating, a transformer is required, in order to yield the direct current.

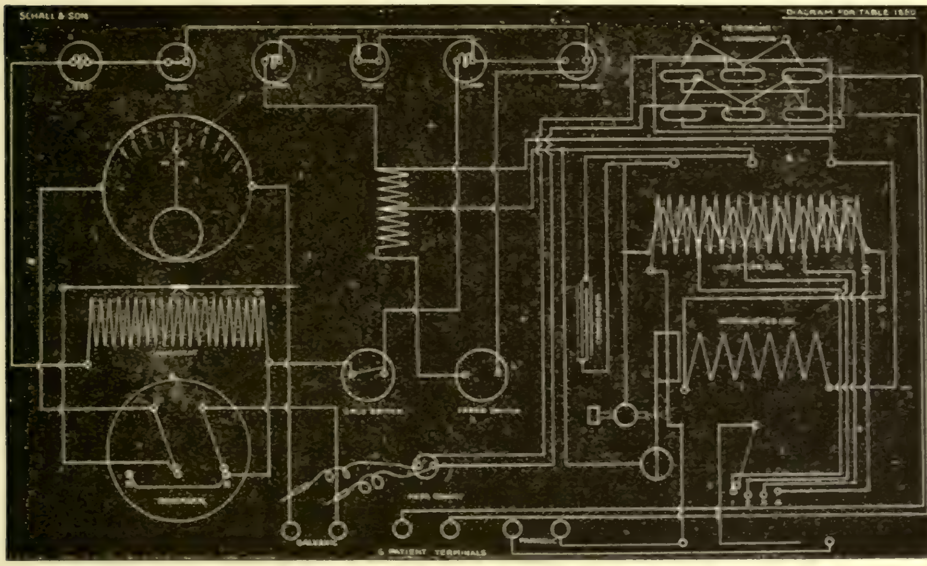


FIG. 225.

For the diathermy machine, an alternating current is necessary, and so if the main supply is direct a motor transformer is necessary to produce the required current for this apparatus.

The Combined Table—comprising

1. Galvanic current ;
2. Faradic coil ;
3. Metronome interrupter (reversing type preferable).

This apparatus suffices for the whole of faradic or galvanic treatment and nerve muscle testing.

The faradic coil is of a special type. It consists essentially of a thick wire coil, with a low internal resistance, which can be easily regulated, and which can be used to produce painless muscle contraction, with a minimal skin effect. A condenser is placed across the make and break

to counteract the sparking. The secondary, which is the current used, is tapped at various points—layers 1, 2, 3, 4, and the current is thus roughly graduated in amount—No. 2 being stronger than No. 1, and so forth. The finer graduations are controlled by pushing and withdrawing a large soft iron core in the primary.

The coil has been designed with the object of producing a current which shall be as nearly as possible painless, and one that is capable of being exactly controlled. Using the longest tapping on the

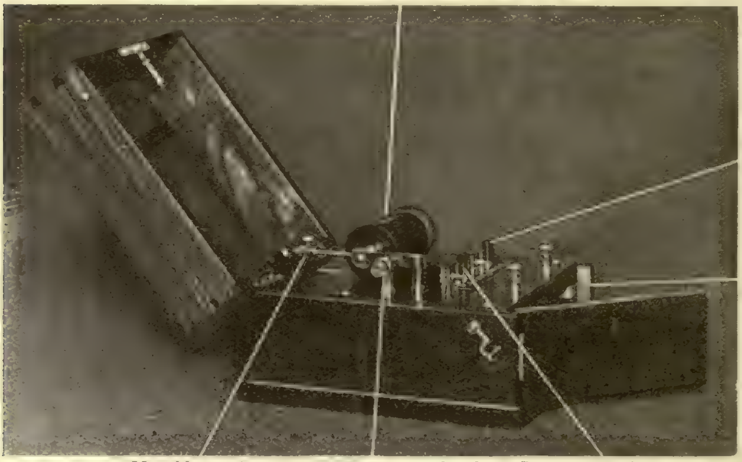


FIG. 226—Battery. Side view.

secondary (layer 4), it is sufficiently powerful to be used as a testing coil. Using the shortest tapping (layer 1), and with the iron core fully withdrawn, it may be used to test the exposed nerve during an operation.

For this latter purpose a dry cell (1·5 volts) is the best form of current supply to use, and in this form the coil is most portable.

Either the faradic or galvanic current may be applied directly or interrupted via the metronome, in using this combined table. It is only at make and break of the galvanic circuit that a muscle contracts, and this make and break is brought about rhythmically by the metronome. When the uninterrupted galvanic current is needed, as e.g. in ionization, the metronome is omitted from the circuit.

Similarly with the faradic. This current, which is in itself an interrupted current, may be applied to the patient either directly or with its secondary output again interrupted via the metronome.

The former method is used for muscle training and muscle regeneration, the latter for testing.

Diathermy. This apparatus yields a current of very high voltage and frequency.

It is actuated by an alternating current supply. Diathermy is an intensive form of high frequency, from which method it has been developed by certain modifications of the apparatus.

Its value as a therapeutic agent lies in its power of producing heat,

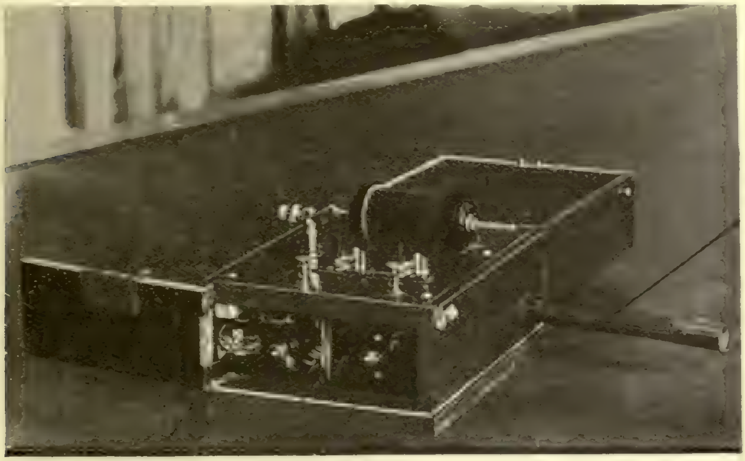


FIG. 227.—Battery. End view, showing core withdrawn.

to any required degree, and localized to any depth and in any part of the body.

High Frequency. The high frequency current is applied for the psychical effect on the patient, and is sometimes useful in hysterical cases.

The effluve obtained from this apparatus is of service in producing counter-irritation in conditions such as trench feet, in which case it often relieves the painful hyper-æsthesia that is associated with it.

Tungsten or Ultra-Violet Lamp Apparatus. This instrument is actuated from the direct current supply.

This treatment is of service in promoting the growth of epithelium in atonic ulcers, and aiding healing in indolent conditions. The radiation from the tungsten arc has been shown spectroscopically to be richer in ultra-violet rays than the radiation from any other source (Schunk).

METHODS OF TREATMENT

Faradic Stimulation of Muscles. The method of graduated contraction.

In order to make the treatment by this method clear, a detailed description of the actual treatment of a muscle group will be given, taking the quadriceps as an example. With the necessary alterations in the position of the pads and so forth, the description is equally applicable to any other muscle or group of muscles.

The patient is placed on a couch with the lower extremity bare. It is not enough to turn up loose trousers, as it is necessary to stimulate high up the thigh. The affected limb has a sandbag placed under the semi-flexed knee in order that it may lie absolutely easily and at rest,

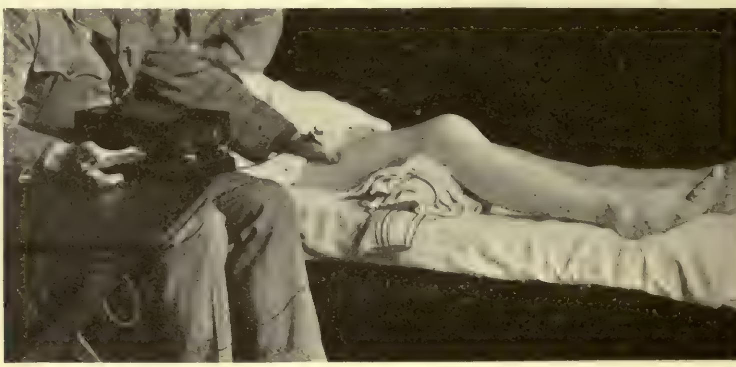


FIG. 228.—Position for stimulation quadriceps. Knee semi-flexed over sandbags and all muscles fully relaxed.

and between the knee and the sandbag, and held in place by the latter, is placed the indifferent electrode. It is a metal plate, roughly five by four inches. This is attached to one terminal of the battery, and it does not matter to which. The plate is covered with two or three layers of lint, made wet (and not merely moistened) with water, to which a little salt has been added. The active electrode, which is a small metal disk about the size of a five-shilling piece, covered with lint and made wet, is grasped in the cleft between the thumb and first finger of the operator's left hand.

The operator sits at the patient's right side with the battery on the combined table in front of him. Everything must be so arranged that the core of the coil can be worked with the right hand, and the patient's muscle comfortably reached with the left.

The active electrode is placed in contact with the quadriceps at a point about the mid-line of the thigh in front, at the junction of the upper and middle thirds.

This is the common point of stimulation for the rectus, crureus, and external vastus.

The electrode is placed on the muscle, and the muscle substance is grasped, together with the electrode, between the thumb and first finger.

These instructions may seem laboured, but it is necessary to feel the amount of contraction, and I have seen so many people fail to grasp the meaning and significance of this simple point that it cannot be too strongly insisted on.

The right hand gradually inserts the core whilst the left appreciates the amount of contraction. The degree of contraction being thus exactly appreciated and controlled, such a degree as is deemed necessary can be

FIG. 229.—Stimulation of quadriceps with extension of the leg. In this case the patient was totally unable to make any voluntary extension on account of the complete wasting and lengthening of the quadriceps from loss of tone, arising from a knee injury.

obtained. The core should be inserted and withdrawn evenly and rhythmically at a rate of about seventy times a minute.

If the muscles are much wasted the leg will not be raised from the couch by the contraction, for the wasted muscles will be lacking in tone and incapable of a normal degree of contraction. But the muscle will be felt to contract by the operator's left hand, the patella will be drawn up slightly, and the ligamentum patellæ rendered tense. If the wasting is only slight, the action of the quadriceps will produce rhythmical extension of the leg.

When this portion of the quadriceps has been treated for some two or three minutes, it should be allowed to rest, and the other two important muscles should be dealt with in turn, viz. vastus internus and the tensor fasciæ femoris.

The point of stimulation for the vastus internus is an inch or two above

and just internal to the lateral border of the patella. When this muscle is contracted it will be seen to have little or no action in raising the patella. It is, in my experience, the muscle that wastes most rapidly and most completely in injuries of the knee. The vastus internus, or rather its lower fibres, appear to act largely as a support to fix the knee, and form a strengthening buttress for the inner part of the capsule and very little as an extensor.

This may also account for the fact that active exercises against resistance—as in the 'stationary bicycle' and various forms of Zander apparatus—have far less effect in restoring the vastus internus than they have on the other members of the quadriceps group.

By graduated contraction the tone of this muscle is restored and function regained as easily as is that of the other muscles, and the treatment therefore presents no difficulty.

The tensor fasciæ femoris is the other important muscle to exercise in cases of quadriceps insufficiency. It can be put into action by stimulating at the outer margin of the thigh in the upper third. It will be obvious when the right point is reached, as the fascia lata (ilio-tibial band) stands out strongly each time the muscle is made to contract. The tensor fasciæ femoris is of the utmost importance in supporting the body-weight in the upright position and with the minimum of effort, and it should be treated regularly and systematically at each sitting. I do not think enough importance is attached to this muscle in treatment of wasted quadriceps.

The treatment of the whole quadriceps group, with a minute or two spent on the adductors, takes about twenty minutes in an average case, but it is not possible to lay down hard and fast rules as to the amount of stimulation required, as this varies with each case. No one point is stimulated for so long a time as to induce fatigue in the muscle. The signs of oncoming fatigue are not easy to describe, but if the muscles be over-exercised the patient will next day complain of stiffness and aching, and recovery is retarded. A markedly wasted muscle group is stimulated for less time than a normal one, and the actual contractions should always be submaximal. This degree of contraction is gradually increased from day to day as the muscle recovers tone with treatment. Experience and the handling of cases can alone guide one as to the amount of treatment which is necessary for any particular case. It is better to do too little than too much. The sign that the muscle has done as much work as is desirable is that the character of the contraction tends to change. In place of the firm physiological contraction of the whole muscle, one sees rather a local contraction in the neighbourhood of the stimulating electrode, and a tremor, or irregular contraction, beginning to result from the stimulation.

After the main quadriceps (rectus, vastus, externus, and crureus) has been dealt with for a minute or so, the vastus internus is stimulated, then the tensor, then the quadriceps again, and so on.

There is one practical point to mention in this connexion, viz. that the stimulus must not be applied too far over to the inner side of the thigh without caution. The marked contraction of the main group, with the free insertion of the core necessary to produce it, is painless ; but if the active electrode is taken over to the inner side and as strongly stimulates the sartorius, it will cause pain. The sartorius is more readily stimulated, probably because the skin resistance is less on the inner side of the thigh, and so may be overstrained and give rise to pain if carelessly or too vigorously dealt with.

During the treatment the patient must be absolutely relaxed. Then the treatment is painless. If he should strain at all it at once gives rise

FIG. 230.—Graduated contraction, first stage. Position of rest. Note position of soft iron core fully withdrawn, and the weight of the arm, supported on a pillow, with all the muscles completely relaxed. Notice position of hand grasping the electrode and the muscle.

to pain. If he moves or strains whilst the contraction is being produced, the muscle must be allowed to relax by withdrawing the core. With a little practice the control is so perfect that even with a nervous patient the whole treatment can be carried out painlessly.

The tone is improved in one sitting, and an amount of contraction, impossible at the start, may be quite easily produced after a few minutes, and the joint moved by the active contraction of the muscle. This effect is only transitory at first, and passes off in an hour or so, but lasts for a longer time after each treatment until the tone is restored permanently.

The method of treating cases is so easy after a little practice that the following instructions may seem superfluous, but I call attention to them here because I know from experience how much more quickly a case

progresses if the operator is experienced than it does if he or she has had but little practice in using this battery.

First and most important, after any one contraction the stimulus must be decreased until complete relaxation takes place. If the muscle is kept partly tetanized it will waste, as has been shown experimentally.

Again, the position of the patient must be such that there is absolutely no strain or muscular effort. In treating the deltoid region or forearm there must be no weight on the shoulder girdle, i.e. the arm must be supported and not simply allowed to hang down. If the lower extremities are being treated the patient lies on a couch with a support under the affected knee.

All screws and connexions with the wire and electrodes must be firm, and the electrodes themselves really wet and not simply moistened. In this way there is no waste of current, and therefore a weak current will produce the contraction. This is desirable, as strong currents naturally tend to become unpleasant and would cause the patient to resist. As regards the position of the pads, the active electrode is always in the left hand, and applied direct to the muscle, or its motor nerve. Broadly speaking, the point of maximum stimulus is at the motor point. It must be remembered that very often—in fact, in most cases—it is a group of muscles rather than an individual muscle which is being treated. The size of the electrode recommended obviates any difficulty.

The three main points of stimulation were noted in dealing with 'quadriceps' cases. Below the knee the motor points suffice for the anterior muscles. The action of these muscles in moving and controlling the ankle-joint can be beautifully shown.

The indifferent electrode may be placed anywhere. It is convenient to place it under the knee in cases in which the lower limb is to be stimulated; between the scapulæ if the upper limb is being dealt with or if the erector spinæ is being redeveloped. When treating the scapular muscles, the indifferent electrode should be placed in the lumbar region. For the flexors of the hand and wrist it should be placed either between the scapulæ or on the inner side of the arm, but in dealing with the extensors of the hand, it is best placed on the back of the wrist. When the indifferent is placed in this situation a more complete control is obtained.

The electrodes should be plain metal, simply covered with a few layers of lint (not sewn on), which can be renewed for each case. As ordinarily supplied, covered with one layer of flannel, it tends to get dry too quickly.

In concluding these instructions on the technique employed I wish to point out the necessity to obtain familiarity with the coil. It looks perfectly easy to contract the muscles gradually and rhythmically in any case, and so it is, but only after practice. Jerky movements of the core

and incomplete relaxation between the contractions are common faults, and I would advise a little practice with normal muscles before injured ones are approached.

The redevelopment of muscle and muscle training, in which the scope for the employment of this method is so great, can be carried out by masseuses or others trained in the use of the coil.

INTERRUPTED GALVANIC STIMULATION

The part must be well soaked as a preliminary to treatment; hot water will suffice, or any of the other forms of heat, such as radiant heat or a paraffin bath. Great care must be taken to avoid damage to an anæsthetic area by heat, as in the case of peripheral nerve injury; damage to tissue is liable to occur at a lower temperature than that which would affect a normal limb.

GALVANIC STIMULATION

The di-polar method, using two small electrodes placed longitudinally on the paralysed muscles, is the method to be adopted. With the two electrodes on the same muscle, there is less spread of the current to the surrounding muscle groups than with the uni-polar method. During treatment the limb is placed on a table or couch in a convenient position with the muscles relaxed. Each muscle is stimulated for a few minutes. During the early stages a small number of contractions are all that is necessary, and as the muscle commences to recover the amount of work it is called upon to do is increased. If the degeneration is so marked that no contraction is obtained by the current it is sometimes possible to obtain a result if a galvanic bath is given for ten minutes as a preliminary. The explanation is that the hyperæmia produced lowers the resistance of the skin and so allows the stimulus to reach the paralysed muscle.

Muscle-nerve Testing. This subject is considered in a preceding section, 'Diagnosis of Injuries of the Peripheral Nerves.' It forms a considerable part of the routine work of the electrical department.

MASSAGE IN ORTHOPÆDIC SURGERY

BY

JAMES B. MENNELL, M.A., M.D., B.C., Cantab, &c.

Medical Officer in Charge of the Massage Department, Special Military Surgical Hospital, Shepherd's Bush; Medical Officer, Physico-therapeutic Department, St. Thomas's Hospital

MASSAGE IN ORTHOPÆDIC SURGERY

THE MASSAGE DEPARTMENT

BEFORE dealing with the many ramifications of the important and varied work done in the Massage Department of a Military Orthopædic Hospital, it is necessary to say a word as to the *personnel* of the staff by whom the massage treatment is carried out.

In the first place it is essential that one particular medical officer should be in control of the department as a whole. No masseuse, however efficient and fully trained, can properly be left in sole control of the treatment to be administered in the department. The masseuse is no diagnostician, and in any complication immediate help from a medical officer is called for. It is therefore a *sine qua non* that the masseuse should have at hand medical advice to which she can appeal at any moment throughout the treatment of her cases.

Then, too, since the use of a Massage Department is primarily to prepare for, and to render complete, the work of the surgeon, it is essential that those whose business it is to work in the department should know exactly what is the end in view when he orders ' massage ' : otherwise co-operation in treatment is impossible. It is therefore of great importance that every case should be seen by the masseuse with a medical man both before treatment begins and at frequent intervals during the course of treatment.

At the same time it is impracticable for every surgeon in the hospital to be in such constant touch with the Massage Department as to be able to dictate and to supervise the treatment of each of his own patients for whom he may have ordered massage. The department must necessarily, therefore, be under the immediate charge of one medical officer.

But the position of the medical officer in charge of the Massage Department is a peculiar one in this respect, that he may have several hundred cases under his care, yet not one of the patients is his only. They are all, so to speak, loaned to him by the surgeons. It is his duty to carry out, to the best of his ability in each individual patient, the wishes of the surgeon who sent the case to him ; and herein lies his greatest difficulty. If the wishes of a surgeon are to be carried out properly, it is imperative that he should make these wishes perfectly clear. This he can only do by meeting the medical officer in charge of the Massage Department at regular intervals, certainly not less frequently than once a week. Without

such meeting he can never know what is being done for his patients, or whether the treatment is such as he desires. It is inevitable that the treatment administered in the department should be influenced in accordance with the experience of the medical officer in charge. His is the guiding hand in all cases, and, however carefully he may endeavour to accord special attention to the wishes of the particular surgeon concerned in each individual case, the performance of the masseuse cannot fail to be subdued to his general teaching, despite explicit demonstration or instruction. Only through consultation, therefore, between the surgeon and the medical officer can it be ensured that the treatment administered is in accordance with the wishes of the former ; or that, if it is not so, opportunity is afforded for discussion, alteration, or adjustment. Discussion, moreover, is frequently required to decide on the relative merits and demerits of a particular sling, bandage, or splint, for it sometimes happens that progress from the physico-therapeutical point of view is hampered by considerations of a purely surgical nature.

It being assumed that the Massage Department is under the immediate control and direction of a medical officer, it is obviously impossible for him, by his own unaided effort, effectively to supervise the treatment of hundreds of patients. He must, of necessity, receive adequate support and assistance from the senior members of his staff. It may be well at this point to attempt a classification of the massage staff in a military hospital. The masseuses employed may be placed in four classes according to the training each has received.

First, there is the fully-trained gymnast from one of the physical training colleges. She holds a certificate which means that she has undergone a course involving a minimum of two years' training, and that her knowledge of educational and medical gymnastics (including massage) is of a high standard. She is not only a trained gymnast herself, but has usually considerable ability as a teacher. ' Cramming ' has found no place in her training, and the only direction in which she is likely to be found lacking is in actual hospital experience. The proportion of masseuses employed in military hospitals who have undergone this magnificent training is unhappily very small.

The second group, which is also regrettably small, comprises those masseuses who have taken full training as a nurse in the wards of a general hospital before studying massage. The value of the combined qualification is inestimable. The pity of it is that so few nurses are willing to undergo what should be considered the ' full ' training, and that the great majority are content to stop short when they have obtained their ' Massage ' certificates.

The third and fourth groups consist of those who hold the certificate of the Incorporated Society of Trained Masseuses for ' Massage ' and

'Swedish Remedial Exercises' (S.R.E.) in the case of the third group, and for 'Massage' only in the case of the fourth. These two groups comprise a vast majority of those who are working in our Massage Departments. No masseuse is allowed to work in a military hospital who is not a member of the Military Massage Service, and the standard qualifying examination for the corps is that for the certificate of the Incorporated Society of Trained Masseuses, only a few members being accepted with other qualifications, notably those with a certificate from a physical training college. Here let me say that the debt of gratitude which the nation owes to the Incorporated Society is all too little recognized. As an examining body it has been the principal moving force in securing to the public a recognized minimum standard of ability and training among practising masseuses. The examinations conducted by the society are four, 'Massage', 'S.R.E.', 'Electrical', and 'Teachers'. With the two last we are not at present concerned.

For the 'Massage' certificate candidates must have had a training of at least six months' duration, and have to pass both written and *viva voce* examinations in anatomy, and in the theory and practice of massage. The practical portion of the examination in massage is made an outstanding feature.

For the 'S.R.E.' examination a further six months' training is demanded. The general character of the examination is similar to that for the 'Massage' certificate, but the standard in anatomy is considerably higher—it would tax the ordinary medical student severely—and for massage is substituted physical treatment by means of exercises.

It is greatly to be regretted that a large proportion of massage students cease their studies on attaining the 'Massage' certificate. When training for the massage examination, students are taught a method of physical treatment by which they are enabled to assist in the cure of a patient; whereas in the S.R.E. course they learn, as their main object, how to teach patients to assist in curing themselves by their own exertions. This comparison is, of course, not altogether exact. The two methods of treatment are really supplementary one to the other. But whereas it is only in exceptional cases that massage treatment alone suffices to cure in orthopædic work, it often happens that S.R.E. training can effect a cure in the total absence of treatment by massage proper, or can complete a cure when massage can no longer be employed with benefit. As a general rule both treatments should be carried out concurrently in the earlier stages.

I would allude here to the training necessary for dealing with the countless 'borderland' cases who still require massage, who are fit to begin elementary exercises, but who are not fit to perform the most simple of S.R.E. tables. These patients require muscle training rather

than muscle exercise. This training of the muscles is a special art, hard to learn, difficult to teach, and calling for the exercise of much patience and tact.

To return to the question of the staff of the Massage Department, it is plain from what has been written above that the medical officer in charge will be wise if, in selecting his senior assistants, he chooses as his first and second in command a qualified gymnast and a fully trained nurse. This combination is essential if two all-important needs are to be met. The nurse's presence is required to supervise and instruct the inexperienced in the art of dealing with dressings and in the adjustment of splints, while her former training will help her in the maintenance of hospital etiquette and discipline. To the gymnast falls the difficult task of teaching the art of muscle training and the gradation of exercises, to that portion of the staff—usually far the larger portion—who have not taken the 'S.R.E.' examination. The head masseuse should rarely undertake the treatment of individual cases ; her time ought to be more than fully occupied in supervision.

Where elementary class-work is undertaken for the treatment by exercises of men who are not yet fit for the gymnasium, this must be under the care of a fully trained gymnast.

It is very important that at least one masseur should be working in the department. All those with experience to whom I have spoken on the subject are unanimous that the general behaviour of patients in the massage departments of military hospitals is exemplary. But a few black sheep there must always be, and it is necessary that these should be treated by a man. Moreover, there is always a certain percentage of cases which from the nature of their injury are unsuitable for treatment by the female staff.

In this connexion a word must be said of the blind masseur. All blind masseurs are, I believe, trained at St. Dunstan's and the National Institute for the Blind. It has been my privilege to work at different times with three of them. Their massage is excellent, and their only limitations are that they are unable to deal with cases requiring dressings, and that they cannot, of course, supervise the performance of active exercises from a distance, though they are competent to deal with muscle training.

The last point calling for remark in connexion with the selection of the staff is this, that at least one member should have been trained in hospital to deal with cases of recent injury. This is an art apart from all other branches of physical treatment ; and, if no one is available with the necessary previous training, the medical officer and his principal assistants should at once set about training one or more individuals so as to fit her or them for this special work.

The Massage Department must work in close co-operation with other departments whose activities are intimately connected with its own. Take, for instance, the Hydrotherapeutical Department. Heat has long been recognized as a valuable adjunct to treatment by massage. The heat applied may be either dry by radiation, or moist by conduction. If massage is to be the main remedial agent, it is better that the heat applied should be by radiation in a hot-air bath, since water tends to render the skin less amenable to manipulation, unless indeed some form of grease or oil is to be used as a lubricant. On the other hand, if the main portion of treatment consists of muscle training or exercises, then heat by conduction should be chosen, the best form being the aëration bath. Dr. Sontag has pointed out that this bath should not be given either too hot or for too long a period, the ideal temperature and duration being 110° and 12 minutes respectively. Whether the heat applied be dry or moist it is important that the heat treatment and massage should be as nearly continuous as may be possible.

The contrast bath serves its own end—gymnastics of the arterioles as Sir Robert Jones has happily dubbed it—and is of no particular value as an adjunct of massage treatment.

The same department deals with a large group of cases for which forcible movement of joints is prescribed. The necessary movement should invariably be given in the 'manipulation bath', i.e. the manipulations should be performed in the aëration bath, which for this purpose should be as hot as the patient can conveniently bear it. After the bath the patient should pass on to the Massage Department, where general massage to the *whole* limb affected is applied in order to reduce as far as possible the reaction from the manipulation, and also to relieve any persistent pain. All attempt at muscle training immediately after the 'manipulation bath' is futile, since pain will almost certainly return, and pain in a joint is the strongest of all inhibitory agencies to muscular activity. At this point massage alone should be given without any further attempt at either active or passive movement; but later on in the day the patient should, as a rule, attend the department a second time for muscle training. The movement prescribed should now be active only, and massage should precede and follow the exercises.

Of one method of combined treatment I have no experience, but theoretically it is very sound, and Major Broad, in charge of the Massage Department at Alder Hey Hospital, speaks of it most highly. This consists of massage treatment given under a 3,000 candle-power light which radiates a very considerable heat. It is worthy of a serious trial.

The same should be said of the paraffin bath in use at the Military Orthopædic Hospital at Leeds, and now recently installed at Shepherd's Bush. The claim is made that the heat from air radiation or water

conduction is far more transient. Indeed its duration from either source may be measured in minutes, while that from the paraffin bath continues for at least an hour. All accounts, both from medical officers and patients, are strongly in its favour. I can well imagine that they are in no way exaggerated.[1]

Take again the Electrical Department. The tendency to divorce its activities from those of the Massage Department is greatly to be deplored. The two should work hand in hand, and it is a pity that geographical considerations so often throw artificial difficulties in the way of co-operation. In an orthopædic hospital there are comparatively few cases that would not benefit from combined treatment. Restoration of function by means of exercise entails voluntary effort on the part of the patient, which is not always forthcoming. There are many cases in which, by electrical stimulation, the muscles can be exercised independently of the goodwill of the patient. The number of voluntary contractions that an enfeebled muscle is capable of performing at any given time is often limited, and, for restoration to be rapid, it is essential that frequent repetition of contraction throughout the day should be ordered. If this is not carried out—and it is impossible to ensure that it is—electrical stimulation can at least enforce that a very considerable number of contractions are performed. On the other hand no great benefit can be bestowed by the mechanical performance of these contractions unless voluntary impulses are encouraged to the uttermost by general exercise or by individual muscle training. Then, too, it is not adequate in cases of paralysis, as after nerve injury, merely to compel contraction of the paralysed muscles by galvanism. The joints throughout the injured limb must be kept supple, and every care should be taken to exercise as fully as possible every non-paralysed muscle provided that no strain is placed upon the weakened muscles. Not only does the exercise maintain the function of the limb at its highest pitch, but it is the only method by which the general circulation through the whole part, the paralysed muscles no less than those that are unaffected, can be adequately maintained. The maintenance of circulation is the work of the Massage Department : the maintenance of contractibility is the function of the Electrical Department ; and the maintenance of efficient circulation through the paralysed muscles cannot but enhance the benefit conferred by the contractions in response to electrical stimulus.

It not infrequently happens that some one muscle in a muscle group is weakened out of proportion to its fellows, as for instance the lower

[1] Since the above was written the paraffin bath has been in use for some time at Shepherd's Bush. It has in every way fulfilled our anticipations and is now in very general use. It has largely supplanted the aëration bath as a preliminary to massage.

fibres of the vastus internus when the whole quadriceps is wasted. It is always a matter of difficulty to build up by exercise any particular muscle element so as to overtake the development of the remainder of the group. The variety of exercises which enable us to do this is small ; the treatment, if exercises alone are employed, is therefore monotonous and calls for great perseverance on the part of the patient. Electrical treatment, on the other hand. renders the process quite simple.

The combination of ionization with massage has been lauded in the treatment of scars. I know that there are many who will not agree with me, but I cannot accept as proven that the combination has any great value. Some scars loosen rapidly in response to massage, others do not. The same may be said of ionization, and I have yet to see any considerable number of cases in which scars, which are not loosening satisfactorily under massage, do so when ionization is added ; or even in which the mobility of the scar is hastened by ionization whenever the response to massage alone is apparently satisfactory. In the treatment of complaints such as sciatica the combination of ionization and massage is often potent for good.

Of the utility of X-ray treatment in orthopædic cases I have no experience, but, to the value of radium treatment I am able to bear limited testimony, thanks to the kindness of Capt. Stevenson of Black Rock Hospital, who first drew my attention to it, and to Dr. Lynham of the Radium Institute, who kindly arranged to carry out the treatment for me. Casual observation of cases before and after treatment by radium is liable to be disappointing, but careful investigation of a considerable number of cases has convinced me, though at first most sceptical, of the undoubted benefit it sometimes confers. In some cases I have failed to note improvement ; in others the improvement made has been most striking. I have not yet adequate experience to be able to foretell results ; but this much may, I think, be fairly said. Scars which hitherto have failed to respond to treatment frequently begin to do so ; stiff joints that seem to have come to a standstill begin to loosen out again ; sensitiveness is often allayed, enabling treatment to advance more vigorously, and some patients themselves bear testimony to the fact that the part feels more natural after treatment, and that joints seem to be less firmly bound down and fixed.

Many cases that enter the Massage Department should pass on ultimately to the Gymnasium. Here close individual supervision is not so easy as when few patients are under instruction at one time in a smaller room. One small movement accurately performed is, in the early stages of remedial work, of far greater value than many more ambitious movements performed in a faulty manner. Constant watching and unfailing care will alone eradicate a fault in movement, and it is far more simple

to prevent the development of 'tricks' than to cure them. Accuracy in movement cannot be inculcated too early, and it is for this reason that I inaugurated the system of elementary class-work for the training, in small groups, of patients who are still unable to take their place in the Gymnasium. Some of the cases in the earliest foot class are not allowed to stand; in the knee class they may not be ready to walk even with a back splint; many patients in a hand class are still wearing cock-up splints; and patients frequently enter a shoulder class while still wearing an abduction splint. It seems to me a great error to suppose that a patient should be able to pass direct from massage and muscle training to the Gymnasium. Either he will arrive there unable to take his place with his fellows; or he will receive an unduly prolonged course of massage treatment, whereas what he really needs is exercise. The gradation from pure massage and muscle training to definite exercise is an art which entails the greatest care, experience, and tact. Yet, where such gradation is properly effected, nothing confers equal benefit and nothing can take its place; and it can only be properly effected by means of class-work, the classes being small, and the exercises elementary.

Elementary class-work has another important advantage in its effect on the psychology of the patients. Many instances are to be found where men who will do little or nothing when working alone, at once do every thing in their power when called upon to do work with their fellows.

It is a mistake to make the outfit of the Massage Department too elaborate. It usually suffices for the masseuses to work in pairs. Between them they share a table, provided with blanket, sheet, three pillows, and a small waterproof sheet (to prevent soiling from boots). Some prefer a high table and some a low, so that it is well to meet all requirements by arranging that the height of some tables should be 34 inches and others 24. They should be 2 feet broad. Elevation at either end is attained by pillows or a bed-rest rather than by any hinged arrangement, though one regular massage plinth at least should be provided with an adjustable back, and one table should be cut so that it can be used as a high plinth. In addition provision should be made for stretching hips or knees by means of constant pressure. A simple method of adjusting the higher massage tables is shown in the illustrations (Figs. 231 and 232).

In addition each pair of masseuses should be provided with at least an ordinary chair, a low chair (of the pattern usually found in any nursery or maternity ward), a four-legged wooden stool, and a two-shelved wooden locker of the regulation ward pattern.

Each masseuse is provided with a dredger containing powder. I have found that the best powder consists of ordinary French chalk, which is sifted and ground up thoroughly with ten minims of oil of Bergamot to the pound. To every eight masseuses is supplied a pot of ointment—

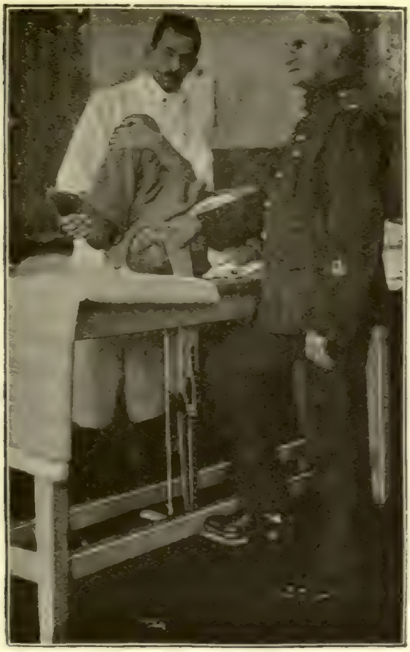


FIG. 231.[1]—To show adaptation of a massage table for the mechanical stretching of an amputation stump.

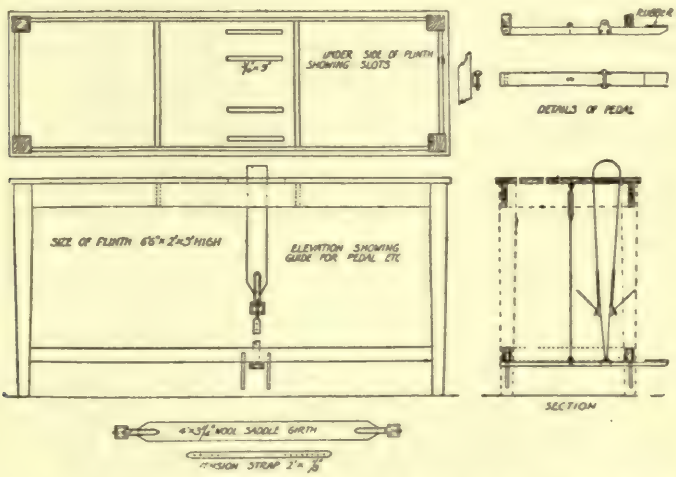


FIG. 232.—Detail drawing of table shown in use in Fig. 231.

[1] This and the two succeeding illustrations are reproduced from the writer's *Massage: Its Principles and Practice*. Published by J. and A. Churchill.

plain vaseline is as good as any—and two Bier's cupping glasses. The most useful sizes are oval, $2\frac{1}{2}$ inches, and circular, $1\frac{3}{4}$ inches and $1\frac{1}{4}$ inches diameter.

In the elementary class-room at Shepherd's Bush I have had fitted up three specially designed exercising outfits. Each consists of a vertical ladder, the rungs projecting on either side. Towards the top a rung is omitted, and the top rung is set forward so as to allow of backward hanging. Two removable upright poles are slotted into the face of the uprights, so that patients who are unable to pronate may still be able to perform ladder exercises. When removed these poles are available for ordinary free pole exercises. Alternatively, into the same slots can be fixed a combined roller and rotator apparatus for exercising the fingers, wrist, and grip, the handles at the end being used for exercising pronation and supination of the fore-arm while standing, rotation at the shoulder being added when sitting.

The lowest rung of the ladder is replaced by a metal bar to which can be attached one end of a sliding-seat apparatus. The height of the other end is adjustable and the foot-piece can be fixed at any given angle. Finally, a three-way weight and pulley apparatus is attached to the vertical uprights of the ladder. The illustration shows the pattern in use at Shepherd's Bush (Fig. 233), which was made by the hospital carpenter, A. J. Hobbs. A large number have been supplied to other hospitals from this source, and the apparatus, with a few modifications, has recently been put on the market by Spencer, Heath & George.

A long plank has been arranged to hook on to the rungs of the ladder so as to render possible exercises on an inclined plane, and a knee-rest in the form of a tall, narrow stool is provided for knee exercises by means of the weight and pulley.

The rest of the outfit of this room consists of numerous odds and ends, such as grip dumb-bells, Indian clubs, one of Colonel Deane's ' Zeppelins ' for encouraging gripping power, a nautical wheel, and so forth.

Round the main room it is well to have a few sets of the ' combined ' apparatus for the use of patients who cannot yet start regular class-work, or who need a dose of exercise more than once a day, but who are not yet fit for the gymnasium.

Personally I am glad to be able to keep a small room apart strictly for the treatment of officers. It is well also that there should be another separate room in which special cases can be treated, chiefly those with neurasthenic complications.

Finally, a room must be set apart as a combined examination room and office. Here all patients are seen on their first attendance, and here consultations with the surgeons are held and periodical inspection of patients is carried out by the medical officer. It is of vital importance that at

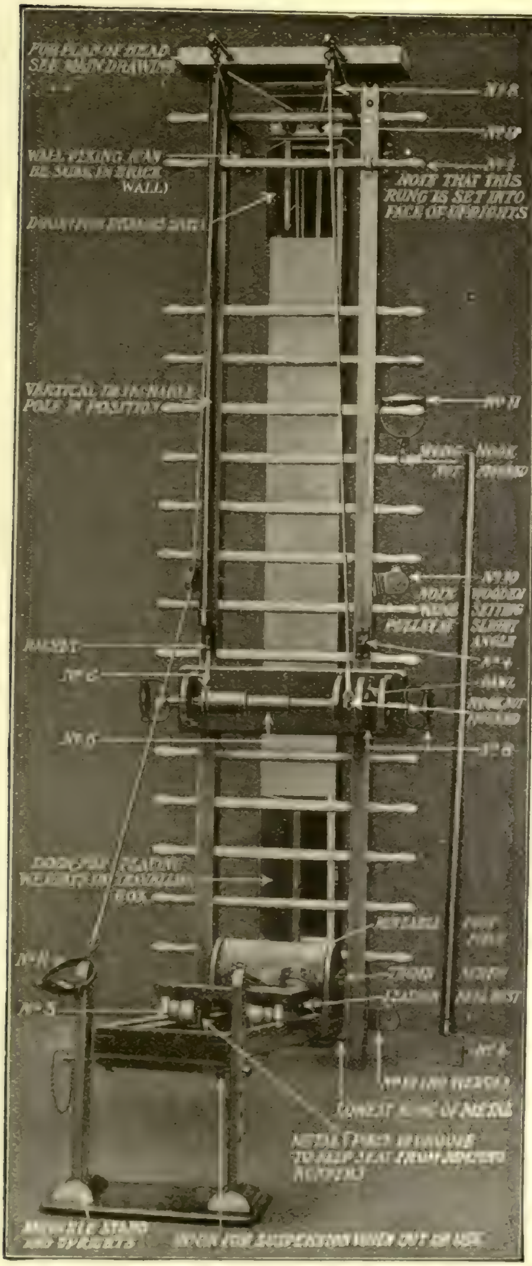


FIG. 233.—Combined apparatus in use in the elementary exercise class-room at the Special Military Surgical Hospital, Shepherd's Bush.

every inspection of patients the masseuse who is responsible for the treatment and the head masseuse should be present.

The amount of pure office work is very large. Each patient should have his own case sheet with all essential details entered thereon, together with a note as to the treatment ordered. Record of the result of consultation with the surgeons is kept in a special book, statistics of attendances are kept in another, a third is devoted to pensioners, in a fourth is recorded every case of absence from treatment and the reason therefor. It is a great saving if every case under treatment, with the name of the surgeon and masseuse, is kept in a book of the 'address book' type; and finally an attendance sheet is necessary, showing when a patient was last seen by the medical officer and which day he wishes to see him again. There is ample work in a large department fully to occupy a whole-time secretary.

The latest instructions from head-quarters demand that each masseuse shall be responsible for the treatment of fifteen to twenty cases a day. Given an hour for lunch, this means that only twenty minutes is available for each patient in a seven and a half hour day. In this connexion I should like to warn medical officers that a masseuse cannot efficiently perform this day's work without detriment to her health, unless the midday meal is substantial and an adequate midday rest is enforced. There is a tendency to cut down both and this must be guarded against by strict regulations.

It is obvious that a spastic paraplegia cannot be treated properly in twenty minutes, neither can a masseuse go from the department to a distant ward, undo and readjust a complicated splint, administer treatment, and return all within the space of twenty minutes. It follows that the 'twenty minute standard' has to be taken as a general average, not as a hard and fast rule. A very few cases may require less time, but those with multiple injuries, e. g. injury to one arm and one leg, or to both arms or both legs, require considerably more. So too, as a rule, do cases treated in the wards. For statistical purposes, therefore, a record is kept of the number of injuries treated rather than of the number of patients, and the average duration of treatment is fixed at twenty minutes. To treat twenty cases a day necessarily involves a very severe strain, and care should be taken in apportioning cases to ensure that mental and physical work are suitably combined. Intelligent muscle training, for instance, involves a mental effort which makes it far more fatiguing than an equal time devoted to pure massage work, and it is painful to see a massense near the end of the day administering mere massage to a patient who should be receiving training, simply because she is too 'done in' to make the mental effort required for efficient muscle training.

THE WORK DONE IN THE MASSAGE DEPARTMENT

The work done in the Massage Department of a Military Orthopædic Hospital may be considered under the following headings :

A. Medical.
B. Surgical.
C. The treatment of recent injury.
D. Co-operation with treatment by splintage and plaster.
E. Re-education of muscle.
F. Re-education of function and co-ordination.
G. Elementary class-work.
H. Treatment of deformities.

A. Medical Cases.

Even in an Orthopædic Hospital a certain number of purely medical cases are sure to find their way into the Massage Department, and these are by no means all out-patient pensioners. Sometimes massage treatment is called for to alleviate the indirect consequences of orthopædic treatment. For example, it is not uncommon for patients who are placed upon an abduction frame for the first time to suffer intensely from flatulence. It is true that a series of enemeta will relieve it, but it is far kinder to the patient to rely on the sure relief of abdominal massage, which, in this case, consists in the main of colon kneading and friction. Any patient, indeed, who is confined to bed is liable to suffer from constipation during the earlier stages, and abdominal massage will often avert the necessity for the use of purgatives.

Sciatica and lumbago are frequently encountered. This is no place to enter into details of treatment. It is, however, a fact that many patients who have received prolonged massage and electrical treatment and are nothing bettered, improve at once when the gluteal region is treated with frictions and deep kneading. It is surprising how many victims of sciatica owe their suffering to fibrositis of this region. It is well recognized that massage treatment for lumbago should always be given trial ; but it is frequently a matter for disappointment that, though relief follows treatment, the pain soon returns. It would return less frequently if the treatment were not overdone, and if greater reliance were placed on that excellent old-fashioned remedy, dry-cupping. The secret of success is to use plenty of grease, to pull the cup away from the patient—not to press it in—and to run it to and fro over as wide an area as possible until the whole surface has a uniform pink coloration.

Other forms of neuritis are sure to be encountered. In this connexion it is well to remember that the symptoms of brachial neuritis are due to

a cervical rib in far more cases than would have been expected a few years ago. The possibility of this cause of the pain must always be kept in mind as it is one which cannot be removed by massage. Most of the cases of neuritis encountered will be found to be traumatic, directly or indirectly, unless we admit that the neuritis of trench-foot is toxic. Massage treatment should begin over an insensitive part and the approach to the sensitive area should be very gradual. It may in fact be impossible to administer direct treatment to this area in the early stages. Neuritis after nerve suture, when regeneration is well advanced, can often be relieved by firm friction over the site of suture.

The suffering of the victim of causalgia is such that any treatment that helps even temporarily should never be withheld. Many a patient who has had practically a sleepless night will, of his own accord, go straight back to his ward after massage treatment, feeling that it has given him a chance to snatch some sound sleep. The patient should be treated in a room apart. He is made as comfortable as circumstances allow, and massage of the surface-stroking variety is started (usually it should be centrifugal) over a wide area around the region of origin of the trunk affected. Thus for median causalgia the treatment begins on the sides and back of the neck, the shoulder region is gradually encroached upon, and slowly an advance is made down the arm and finally over the back of the fore-arm. If the patient is still restless in spite of relief, a short dose of head massage may send him sound asleep on the spot. If the pain is in one of the nerves of the leg, massage should start over the lower dorsal and upper lumbar regions. To relieve pain after amputation a similar procedure is followed. Some patients cannot tolerate surface work: pressure with a fixed grip which alternately increases and diminishes, but never completely relaxes, should then be given trial.

Circulatory disturbances are frequent in the massage room. Many take the form of œdema, and, although the cause is surgical—usually combined trauma and sepsis—these may be counted as medical cases. Two points are worthy of emphasis. First, the masseuse must be made fully to understand the truth of Wharton Hood's *mot* that it is no use trying to empty a bottle with the stopper still in place. Applied to œdema, this signifies that it is useless squeezing exuded lymph from the lymphatic spaces of, say, the foot into those of the leg, if these are already waterlogged. Empty these first into those of the thigh and then the foot can be attacked with some hope of success. Then, second, massage for twenty minutes—or even sixty for that matter—cannot counteract the effect of gravity acting for from twelve to sixteen hours. As every one knows, the foot of a healthy leg will swell as the result of prolonged standing without motion. Every patient who suffers from œdema should be compelled to elevate the swollen limb, be it arm or leg, for definite

periods during the day. These periods should be slowly decreased in duration and frequency, massage being used to replace in part muscular activity and to restore as far as possible the circulation. Any increase in œdema must be regarded as a signal, not for an increase in massage, but for an increased dose of elevation. But the real cure is the restoration of muscular activity, and every means available should be used freely to exercise every muscle in the limb that is capable of contraction. As soon as a patient realizes that his freedom depends on the extent to which he keeps his muscles—not necessarily his limb—in action, the need for elevation rapidly decreases and, incidentally, his muscular development proceeds apace. But massage for œdema without adequate elevation is sheer waste of time. Recumbency, moreover, is no less important for chronic œdema of the hand than it is for that of the foot, if flexion at the elbow in a sling to beyond a right angle proves insufficient.

The countless varieties of treatment that have been advocated for 'trench-foot' bear eloquent testimony to the grave difficulties in the way of success. I believe the secret to lie in a combination of treatment. Massage, in full dose, should be given to the thigh and to as much of the leg as is not hypersensitive. The treatment is chiefly deep up-stroking and kneading. The sensitive area is then gradually encroached upon till the whole limb can be treated. It is often possible to 'grab' the patient's foot, hold it firmly and then perform slow, deep, circular frictions without loosening the grasp, long before any surface work is in any way tolerable. But massage alone is but a poor remedy on which to rely. The patient must be compelled to exercise, as freely as possible, every muscle over which he still has control, and those that he cannot exercise for himself must be exercised for him by means of electricity. It should be unnecessary to add, but unfortunately the warning appears to be much needed, that no patient suffering from trench-foot should ever be allowed to bear the weight of his body on his feet until his muscles are sufficiently restored to support the arches, either alone or with the assistance of an outside iron and valgus T-strap. To allow trench-foot patients to loaf about in heelless slippers is an unpardonable oversight. I have seen scores of feet wellnigh permanently crippled through this neglect of an elementary orthopædic principle.

A word must suffice for the treatment of 'shell-shock', neurasthenia, and hysterical patients. Buzzard divides 'shell-shock' cases into seven groups. These are:

(1) Cases of pure exhaustion, who of course require rest, and often massage, as for neurasthenia.

(2) Those 'who have inherited neuropathic or psychopathic tendencies and in whom the process of exhaustion has excited these dormant tendencies into activity'. These are psychical lesions and require psychical

treatment. Massage may be invoked to aid restoration from the exhaustion.

(3) ‘Martial misfits’—men temperamentally unfit for service—usually coming under care as neurasthenics.

(4) Men who have had actual concussion, and who, if allowed about too early on account of apparent ‘rapid recovery’, usually develop neurasthenic symptoms.

(5) Cases of mistaken diagnosis, who really have some organic lesion, and who therefore require appropriate treatment.

(6) Hysterical cases—a large group—including paralysis and spasmodic contractions of every variety, and functional disorders of the special senses, e.g. blindness, aphonia, &c.

(7) Malingerers. Of these Buzzard says, ‘My belief in the general honesty of the human mind leads me to the conclusion that such persons are extremely rare.’ The possibility of malingering must, however, always be kept in mind. Though it is probable that many cases belonging to this group fail to reach this country, some will be found in almost every hospital.

‘Shell-shock cases’ are thus, for the most part, either neurasthenic, hysteric, or psychasthenic. No form of physical treatment can cure the psychasthenics, they call for psychical treatment and physical remedies rarely even assist.

Hysteria is a psychical phenomenon and there is invariably a conflict between the conscious and the subconscious. The former believes in the presence of a lesion, the latter knows that none exists. If we prescribe massage, we are conveying to the conscious mind the idea that we believe in the actual physical disability which calls for treatment; and thus, as it were, we ‘back up’ the conscious against the subconscious and may tend to confirm the delusion. Hence we see that massage treatment of the hysteric is a grave error with great potentialities for evil. No case of hysteria, therefore, should ever be given massage, unless indeed it is administered in a form that amounts to severe physical punishment; and this is a degradation of the art. Other means are alike more effective and more humane. Treatment may be purely psychical, e.g. hypnotic suggestion; even strict isolation may be all that is required to effect a cure; or it may consist of a mixture of much psychical suggestion, backed by a small amount of physical treatment. The choice of physical treatment varies. For paralysis the faradic current is usually chosen; for contractures faradism of the antagonists is often a valuable aid. High frequency and the static spark are useful for hysterical aches and pains, and for treating some deformities.

But there are two forms of treatment that call for special mention here, the disadvantage of both being the long duration of skilled treat-

ment required. They are both intensive and are based on securing fatigue.

Thus hysterical contraction can be overcome by the simple, if somewhat exhausting and painful, process of gradually undoing the contracture, by means of manual pressure, as often as it recurs. In a case of hysterical inversion of foot, for example, the patient is placed on a couch, and the foot is slowly but very firmly pulled round into full eversion. The operator then lets go and the inversion returns. As soon as it is established the process is repeated, until finally the invertors are 'fagged out' and incapable of restoring the inversion. The patient is then made to walk freely and the treatment is repeated next day if the deformity returns. It rarely does so !

The second method amounts to scientific bullying, and is applicable chiefly to hysterical paralysis. The patient is taken into a separate room and is then told that he will go out cured. He is invited to give voluntary acquiescence in the treatment and is warned that it may be protracted. It is then proved to him—this is always quite simple—that some muscle or another is in contraction and therefore not paralysed. If the masseuse calls upon the patient to keep this muscle contracted, he is almost certain to allow it to relax. The very fact of relaxation of one muscle or muscle group usually leads to the contraction of another. Few patients are able to maintain true flaccidity under all circumstances throughout a whole limb or even a small portion of it. The new contraction is demonstrated as well as the antecedent relaxation, and so, by slow degrees, the visible contraction of each muscle is pointed out, together with the result of the contraction, till every part of the limb has been gone through. Whatever the duration of treatment, it must be continued until the patient's resistance is overcome, the visible sign of the inward victory of the subconscious over the conscious being invariably a more or less severe hysterical outburst, often evinced by uncontrollable crying. But the treatment is exhausting to both concerned.

Psychologists and neurologists alike are agreed that neurasthenia is an illness that owes its origin entirely to fatigue—mental, physical, or, more usually, a combination of both. In this illness massage, if administered correctly, is probably the most valuable remedial agent at our disposal : if the technique is incorrect it can, perhaps more than any other means, push the patient farther down the hill. As the common origin of all the varied symptoms is fatigue, the obvious treatment is to ensure rest. Massage can do this far more easily than any other known agency. Since the cause is physical, psychical treatment is unavailing, even to remove what appear to be psychical symptoms. Insomnia is a common symptom and one of the most distressing : fortunately it is equally the most easy to overcome under the influence of massage. But the treat-

ment must be carried out correctly, and although it is impossible here to describe it in detail, the following three laws must, at least, be scrupulously obeyed :

1. 'Only the most gentle movements possible are to be performed : any irritating (so-called stimulating) movements are to be prohibited.

2. 'Any point that is tender or hypersensitive is the last that should receive attention.

3. 'The actual nature of the massage movement performed is of minor importance provided it is rhythmical.'[1]

The importance of observing the second of these laws was seen in the case of an officer who had a severe wound of his arm, made an incomplete recovery, and managed to get into the firing line again only to be wounded in the leg. Amputation followed through the middle of the thigh. Pronounced insomnia, attributed by the patient to pain in the stump, was gradually wearing him out, and a few weeks after the operation his appearance was haggard and wild, his mental condition corresponding to his physical. All drugs, including free use of morphine, had failed to alleviate. Three weeks after massage treatment began he was sleeping well and his pain had gone. But the treatment was directed entirely to his back, neck, and head, the stump being left severely alone when it was found to be hypersensitive. Had it been treated, there is little doubt that the patient would have gone from bad to worse.

It must be remembered that not every masseuse is a fit and proper person to treat a neurasthenic ; special skill and temperament are essential to success.

There remains a fairly large group of cases in which psychical symptoms develop in connexion with purely physical lesions. A case in point was a patient with a painful scar on the back of the fore-arm. He had received 'massage' treatment for two months but still suffered from apparently complete paralysis of the extensors. I demonstrated the case to one party of visitors, showing how to secure contraction. I tried to repeat the experiment subsequently on the same afternoon for the edification of another party, but the power of dorsiflexion, though weak, was maintained in every position of the limb, and the 'paralysis' had vanished for good. All the treatment required for this case was to encourage the patient to grip a thick pole in supination, and to do so in various positions until it was done in pronation, when dorsiflexion was maintained. A short course of ordinary gymnastics soon restored strength.

As a rule, however, these cases call for great perseverance, skill, and tact. The physical lesion must be treated, but so too must the psychical element, and the greatest care must be exercised in selecting a masseuse

[1] Quoted from a paper read by the writer before the Medical Society of London and published in the *Practitioner*, January 1914.

to administer the treatment, and in explaining to her the exact condition and how treatment is to be carried out. Massage without muscle re-education is useless ; and in many cases proper splintage is also necessary, which will probably require adjustment from day to day. While the massage and splintage should be regarded as remedial, it is the muscle education that is curative.

B. Surgical Cases.

Treatment of surgical cases in a Massage Department may be required either as a preventive or as a curative agent, and may be ordered before or after operation.

As a preventive measure massage is used chiefly to ensure that joints which have not received injury maintain their mobility, and that the whole musculature, despite injury, is kept in as good condition as circumstances allow. Perhaps the most tedious and disappointing work we are called upon to do is to try to restore mobility to joints in a foot which, with but little care and attention, need never have become stiff. So, too, in the upper extremity, it is a frequent occurrence to find men with their digits almost rigid, although the injury may have been in the upper arm, or with shoulder movement limited to only a few degrees of abduction after a wound of the fore-arm or hand. Another type of wound that cries for preventive treatment is that of nerve injury. The contractures that follow section of the ulnar nerve, for example, would rarely, if ever, be seen, were preventive massage and mobilization administered, and the same may be said of rigidity of the metacarpo-phalangeal joints after injury to the musculo-spiral nerve. There are also many instances of flexion and abduction deformity in cases of amputation through the thigh, of flexion of knee after amputation below the joint, and of contracture of the shoulder muscles after amputation in the upper extremity, many of which could and should have been prevented from developing by timely preventive treatment.

It is surprising how rapidly some of these deformities can develop in the presence of sepsis, and how excessively difficult they are to overcome when once established. There are two facts which seem to be worthy of emphasis and call for wider recognition. First, that skilled massage and mobilization can be administered at a far earlier period after injury than is usually allowed. Second, that although it is usually possible by these means to maintain any mobility which may be present, yet, while septic processes are still active and for a considerable time afterwards, it is not only risky but often impossible to increase mobility in the joints. This applies not only to the joints near the seat of injury but very often to all joints of the limb affected, however remote, both on the distal side and, also in a less degree, on the proximal. The cause is not far to seek. Any attempt to stretch contracted tissue—be it muscular, ligamentous, or

fibrous—or the rupture of any pathological band, however minute, is in effect the infliction of injury. This may be minute, it is none the less real. Whether small or great, efficient circulation both of blood and lymph is necessary to restore the stretched or damaged tissues. After the severe damage to soft structures incidental to most injuries of war, it is inevitable that the vascular system should sustain injury, and that the lymphatics should, in addition, be deleteriously affected by the intense sepsis. Thus repair of structures distal to the main injury is impeded by inefficient vascular supply ; that of proximal structures is impaired by tainted or infected lymph supply. Here then we see at once the difference between the treatment it is possible to mete out after the non-septic injuries of civilian life and after the compound wounds of warfare. For example, mobilization under anæsthetic of fingers that have become stiff after a simple fracture of the humerus is a remedial operation crowned with success—unless the joints are unhealthy from gouty changes or osteo-arthritis—whereas a similar proceeding after a gunshot wound of humerus leads invariably to disaster and the patient is far worse off than before. Hence it comes about that there are three possible methods of correcting deformity due to contracture or rigidity as a sequel to septic gunshot injuries, namely, by the use of slow constant tension, or by gradual pressure with splintage, or by full manipulation and subsequent fixation in plaster. Very slight mobilization under repeated anæsthetics offers a fourth chance of success.

Hence we see the need for a wider recognition of the value of early preventive treatment. A common practice is to refrain from ordering ' massage ' until wounds have healed. The delusion that this delay is a necessity should be strenuously combated ; but not every masseuse should be entrusted with the care of cases whose wounds are still unhealed. If drainage is adequate, mobilization by skilled hands does nothing to increase the risk once the acute stage has subsided ; it may well make all the difference between restoring the limb, and leaving it wellnigh useless for months, and sometimes even with permanent deformity. It can certainly save many operations and much suffering.

Curative treatment is intimately connected with preventive, and must be considered under two main headings, pre- and post-operative.

In preparation for operation, massage is often an important factor. The skin may be unhealthy : its condition may often be improved. This is done by attracting all the blood we can to the part, by means of exercise of all the muscles that have power to act. General massage, often quite short if any considerable amount of exercise has been taken, succeeds and may also precede the active movement, and then the skin is

picked up and rolled between finger and thumb, oil frequently being used as a lubricant. Dry-cupping is often of great assistance and should be performed with Bier's suction cup.

Not infrequently operation must be delayed because of the general poor nutrition of a limb. This is particularly noticeable in cases of trench-foot, when correction of deformity by plaster or open operation may need to be postponed for a considerable time. Here haste and disaster go hand in hand. Little need be added to what has already been said of the treatment of œdema. Free exercise of all the muscles that can be used is essential, even though the patient may not be able to stand. The massage to be administered to assist the circulation through the limb must not be too vigorous. To assist the venous and lymphatic flow a pressure equal to some 10 mm. Hg is adequate, provided the muscles are completely relaxed. Massage over a contracted muscle is futile, as the contraction has already emptied the veins and lymphatics within it far more efficiently than can massage. Then, too, in relaxation no great force is required to exert mechanical pressure on the arterioles, and an important aim in our work is to assist the 'toning up' of the arterioles by the reflex response of the unstriped muscle in their walls to mechanical stimulation. Undue pressure can only result in driving the blood in the arterioles against the stream, a proceeding devoid of scientific excuse. It is probable that over-stimulation of the unstriped muscle leads to a temporary paralytic dilatation of the vessels—surely a deleterious effect with two possible exceptions. The first comprises a group of cases in which there is apparently vaso-motor spasm, as in Raynaud's disease and some cases of trench-foot. The second includes cases of chronic œdema, where considerable vigour of manipulation apparently breaks up the treacly or semi-clotted lymph. Then, too, the dilatation of the arterioles leads to an outpouring of lymph which dilutes, as it were, the semi-solid œdema and so enables it to flow away along its natural paths.

Massage treatment that aims at assisting the circulation should, then, be performed only when the muscles are relaxed and should, as a rule, not be too vigorous. A general 'shake' of the musculature of the whole limb may be used as an incentive to exercise. It should not cause actual pain or it may prove inhibitory to active contraction; it should be invigorating, and partake of the nature of the 'massage' received in a Turkish bath from an unusually skilled rubber. Though the shaking may be vigorous, the pressure must not be great, and the treatment must be administered over as wide an area as possible. Every care should be taken to prevent over-stimulation at any one spot.

But there may be impediment even to massage for the circulation in the form of pain, sensitiveness, or neuritis. The difficulty can always be overcome by the exercise of patience. It cannot be too strongly emphasized

that in all remedial treatment the entire part in question, or even the whole body, must be considered as a single entity. Improvement in the condition of the bodily health is a strong factor in restoring the condition of an injured limb ; and so, too, any treatment that can benefit one segment of a limb will assist the recovery of the whole limb. Thus, though it may be impossible to treat hand or foot on account of sensitiveness, it is still possible to aid their restoration by massage of those portions that can be treated without pain. Day by day the sensitive area is encroached upon more and more, till finally the whole limb can be treated. Direct attack on the sensitive area is not only useless, it often definitely retards recovery in addition to causing much unnecessary suffering.

Prior to operation it may be necessary to loosen either an adherent scar or some stiff joint. These possible results of injury should be kept in mind by the surgeon from the very first, as curative treatment is far less effective than prophylaxis. We can well imagine how hopeless a task curative treatment in the Massage Department may be, when it is remembered that a surgeon in the operating theatre, even with abundant help, not infrequently fails to secure any increase whatever in the movement of a knee, and that the patella will often give way sooner than the adhesions which obstruct movement.

Again, take the case of the stiff finger—not the finger of civil practice which can be ' broken down ' under an anæsthetic with admirable result, but the stiff finger we so often encounter after war injuries to any part of the upper extremity. We know that forcible manipulation under anæsthesia is followed by reaction which leaves the patient as bad as or even worse than before, and that constant gentle traction by splintage (which operates all day and night) may entirely fail, or may succeed only when applied for two or more weeks. Even then, if splintage is abandoned suddenly, the rigidity returns in the former position. If, in the massage-room, we try to imitate in a smaller degree the forceful procedure of the operating theatre, we encounter the same reaction, also of course in smaller degree but with the same unfavourable result. The only hope is to push joint movement to the farthest point which can be attained without reaction following. There is only one way to judge how far this may be, and that is by the amount of pain inflicted and by the length of time required for it to pass off. As a rule any pain that passes off in, say, twenty minutes is not detrimental. Severe pain as a rule indicates that actual damage is being done. The proof can be seen next day. If there is increase of swelling or of pain, or decrease in active mobility, then too much has been attempted. The masseuse should understand that if she never does too much the chances are that she rarely does

enough ; but, at the same time, she must also realize that it is her duty to own up at once when she has overshot the mark, to abandon all attempts to press movement till the reaction has passed off, and then to resume her efforts with reduced vigour. The loosening process is long and tedious, but should be persevered with as long as improvement lasts. A 'dead point' is often reached, and then help under anæsthesia just past this point and *no more* may enable us to carry on again.

But it must be realized that each joint requires individual attention and that promiscuous waggling to and fro is useless. Even in the fingers and toes six movements are possible at each joint, flexion, extension, adduction, abduction, internal and external rotation. All these movements must be performed, but before and while attempting to secure any of them tension in the long axis of the digit should be employed. Then the movement should be performed slowly and steadily, while the patient assists by contracting the muscles which perform it whenever possible. If he contracts the antagonists we shall only succeed in straining or possibly even in tearing their muscle fibres with disastrous results. Our movements, therefore, must be either purely passive, i. e. every muscle in the patient's limb must be fully relaxed, or they must be assistive.

The futility of attempting to mobilize a joint against the resistance of the patient's muscles is best seen in cases of knee-joint injury. The quadriceps, unless wasted away to a most unusual impotence, can resist any and every attempt to flex the knee, and that, too, without undue strain, up to a force equal to the body-weight. So also can the brachialis anticus oppose extension of the elbow. To secure movement in these directions, therefore, the patient must either voluntarily relax the muscles, or their relaxation must be secured by contraction of the antagonists—the hamstrings in the case of the knee, the triceps in that of the elbow. Otherwise we merely tend to strengthen the muscles that oppose the movement by giving them a dose of exercise or, if they are too feeble to resist us, they are more or less severely damaged by an overdose of eccentric resistive exercise.

Thus we see that movement of a stiff joint as a manœuvre of massage should be encouraged as an assistive exercise, and that the stress laid upon the part should be limited to that which does not produce more than a very transient reaction. But if we remember that, in the presence of active or of latent sepsis, it is an easy matter to maintain any mobility that is present in a limb, while it is almost hopeless to attempt to increase it, the value of prophylactic early treatment is at once apparent.

Stiffness in a joint is not necessarily caused by any inherent change in its component parts, it is often due to adherent scar

tissue in the neighbourhood, or in the muscles which control the movement of the joint. When the soft structures alone are involved the scarring has to be very extensive to impede movement, but if the scar itself is adherent to bone the proposition is different.

Were we able by a single movement to tear away, as it were, the root of the scar from the bone without inflicting damage on the healthy structures, all would be well. But the strength of scar tissue is phenomenal ; and there are probably many cases in which a bone would break before the scar tissue would give way, as is the case with many ligaments in the body.

If an attempt is made to loosen the scar by repeated minor efforts, the only result is that the scar tissue is damaged, repair has to take place, and the strength of the scar is thus built up rather than diminished. There are, therefore, three ways in which a scar can be loosened when adherent to bone. The first is by constant tension which slowly stretches it, the second is by leaving it at rest free from active strain while by massage and manipulation everything possible is done to hasten the repair of the damaged tissue, and the third as the result of the normal function of the limb.

General massage can assist towards this end ; cupping performed with the technique already described can do as much or even more. But, as in all curative work, nature can do better still. Voluntary muscular effort is the great curative agent, and this can be assisted artificially. The scar is fixed between finger and thumb, and the patient is called upon to contract his muscles. The scarred mass is then pushed alternately up and down the long axis of the limb and held in position while the contractions are performed ; next it is pushed as far as possible transversely first to one side and then to the other.

It must always be remembered that scar tissue is far more extensive than would appear from the surface appearance. A scar may be likened to the trunk of a tree. The roots are out of sight and their ramifications wide and numerous. To loosen the scar the most distant rootlets call for attention, and until these are dealt with nothing we can do to the visible part of the scar will have any beneficial effect. The whole muscle group involved should be shaken freely from origin or insertion—or better still, if circumstances allow, from both—towards the central part of the scar. If by this means the rootlets can be loosened, there may be no great difficulty in securing in due course the loosening of the roots and finally of the main scar.

It will be seen, then, that to loosen a quadriceps which is bound down to bone by extensive scar tissue is a long and tedious process. Constant tension by splintage not infrequently fails—particularly if the surgeon falls to the temptation of hurrying—and forcible movement

followed by fixation also partakes of the nature of a gamble. Thus it often happens that the masseuse is left to tackle the problem : she will fail unless the scar is 'rested' by the surgeon between the treatments. Impatience on her part is as disastrous as on the surgeon's.

Sometimes lack of mobility in a joint is simply due to contraction of some muscle or muscle group, as for instance of the teres major or psoas, the muscles themselves being healthy and uninjured. In these cases stretching in the massage-room frequently yields excellent results, so much so that the special table shown on p. 513 was devised on purpose to deal with flexion deformity after amputation through the thigh. This gives the key to treatment. The pressure exerted must be slowly applied and continuous in action. Forcible jerking finds no place. Both hands are free for manipulation over the tightened structures. Extension of the knee, when the hamstrings are contracted, can be secured though less easily (the patient being prone or supine), and the table can also be used to assist flexion of the knee in cases of amputation through the leg, the patient in this instance being supine with the thigh at right angles to the trunk. Sometimes deficient extension of the knee is very difficult to correct even when the thigh has not been obviously damaged. The only reason I can propose for this otherwise inexplicable phenomenon is that the posterior ligaments of the joint have been bathed in lymph infected by the sepsis, and that this has, as it were, infected the ligaments without actually infecting the joint itself. Also the fact that we cannot hyper-extend the knee renders it impossible to stretch the shortened tissues beyond a certain point. The same applies when we try to secure the last few degrees of extension in the elbow. Abduction of the shoulder is frequently slow also, chiefly owing to the extraordinary readiness with which the teres major converts itself into an apparently inextensible band. The lower border of the pectoralis major is also an offender in this direction.

Sometimes, prior to operation, we are asked to prepare a scarred area for the surgeon. Dry-cupping is a remedy which may well be added to the other means already mentioned.

Intimately associated with the treatment of scars is that of wounds healing by granulation. The inefficacy of dressings as a means of assisting the healing of a wound which refuses to heal is attested by the great variety of dressings recommended for this purpose ; and this is not to be wondered at when we consider the cause of delay in healing. Repair depends on adequate vascular supply. One of the inherent properties of scar tissue is to contract and to obliterate blood-vessels. Thus, when we are faced with any extensive wound, we can only anticipate that, as healing progresses, the process will become slower in proportion

to the period of time during which cicatricial contraction has been allowed to take place in the surrounding (and already healed) tissues. If this process is allowed to proceed unchecked a time must come sooner or later when the blood supply to the unhealed area will be so far cut off that further repair is impossible. Few wounds would take so long to heal were this more fully recognized and steps taken to counteract the inimical processes at work. This can be done readily and easily in the Massage Department.

First, everything must be done to secure the best possible supply of blood to the whole part by exercise when this is possible and by massage when it is not. Next, deep frictions of small amplitude are performed all round the raw surface, beginning at a considerable distance from the growing edge and gradually approaching it. It is almost essential to use some form of ointment as a lubricant. Free use of dry-cupping all round the scar is also of great assistance. If there is profuse discharge and the skin is infected, cupping is liable to produce a pustular rash and should then be abandoned. Fine vibrations are given directly over the raw surface through a piece of gauze dressing. If the wound is pit-like or very sluggish an even more direct attack can be made with advantage. The tips of a pair of dissecting forceps are surrounded with cotton-wool wrapped firmly round them. This is then dipped into full-strength hydrogen peroxide and the whole granulating surface is rubbed therewith—I had actually written ' scrubbed '—until it becomes plain that further treatment would give rise to active oozing of blood from the granulations. The rapidity with which the most indolent and unpromising of scars will respond to this treatment will prove a revelation to those who have not made trial of it. Moreover, if by this means healing can be promoted, massage and manipulation are surely not less successful when used as a prophylactic measure for extensive wounds that tend to break down again and again. I have overcome this tendency even when grafting had been tried with temporary success and failed.

The question then arises, at what stage can this treatment be started ? For my own part I would say as soon as the temperature is normal and all evidence of acute sepsis has subsided. I have frequently administered massage to a limb while still suppurating freely, with drainage tubes still in position, and have never yet had cause to regret it. Provided drainage is adequate, there is less fear of doing harm, of spreading or even of lighting up sepsis, by means of massage treatment near an open wound than there is in giving similar treatment near a wound that has recently healed completely or in the neighbourhood of an open sinus. It is even true to go further and say that massage treatment, and particularly mobilization, may, in the case of open wounds, prevent the tracking of pus and the formation of pockets.

And let us also remember this. If massage can restore vitality to the tissues surrounding an indolent ulcer sufficiently to ensure healing when progress has been negative for months or even, as in the case of varicose ulcers, for years, it must surely act beneficially when applied to wounded areas of more recent origin. In actual practice we find that the early massage treatment of wounds not only hastens the healing process but also acts prophylactically in preventing altogether (or at least in materially reducing) the disastrous sequelæ common to all wounds that are left to granulate slowly without treatment.

On several occasions mobility has been maintained when tendon-sheaths have been opened for sepsis, but this can only be done if treatment is ordered at the earliest possible moment and before granulation has visibly commenced. The one danger is inadequate drainage.

The greatest advantage gained by the early treatment of recent wounds is the limitation it seems to set to the formation of scar tissue. Scarring there must be ; but the tissue formed can be kept loose and supple, and adhesion to bone, or of one muscle group to another, can be reduced to insignificant proportions.

In cases of compound fractures the extent to which massage treatment can help in the early stages must of necessity depend on the nature of the retention apparatus in use. If enough of the limb can be exposed for treatment without disturbing the fragments, in skilled hands they will not be disturbed by the treatment itself. The two essential points to remember, however, are that drainage must be adequate and free, and that it is playing with fire to start massage treatment when a septic wound is only partially healed over. Far better then to wait till the wound is completely covered with granulation tissue, and even so, if a sinus is present—the drainage being neither free nor adequate—occasional flares will occur. But the same may be said of any wound under similar conditions, and the treatment, though sure to receive the blame, does not necessarily deserve it. Not every masseuse be it noted is fit to be entrusted with the care of a patient with an open wound.

One of the reasons, perhaps, that surgeons are so inclined to hesitate to order early massage in septic cases is that they fail to recognize the almost limitless variations of technique which are possible when performing massage treatment. Many of them are familiar with the custom of sending patients to the Massage Department immediately prior to operation intending to use the result of treatment diagnostically. If the old wound flares up, operation is postponed : if it fails to flare, the presumption is that operation will not be attended by grave risk of sepsis ; but it is not, perhaps, sufficiently realized how greatly the technique

used in this type of case differs from that applicable to a case in which the wound is still open.

Treatment in the one might be likened to the work of a navvy in a quarry, in the other to that of a sculptor putting the finishing touches to his *chef d'œuvre*. For diagnostic purposes we use pinching and dry-cupping pushed to the uttermost limit, wringing-movements, vigorous shaking, beating and frictions even with the knuckles, and I think it no abuse of treatment if next day there is evidence of discoloration from bruising.

The treatment of a patient with a recent wound, however, requires a delicacy of touch and movement that bespeaks long training and special aptitude. The gentlest of touch and absolute rhythm are the essentials ; the only movements are stroking and the lightest of vibrations. The stroking too must be the lightest possible touch on the surface at the start, and any pressure it may seem wise to give is added by imperceptible stages. Even if it is possible only to use the tip of one finger between two scars, much may yet be done.

No thoughtful worker in the Massage Department of a military hospital can fail to notice one blot that remains in our treatment of gunshot wounds of bones. The structural repair of the bone itself is, generally speaking, incomparably better now than it was in the early stages of the war. But our patients are likely to return us small thanks if, while we restore length and form to a femur, we doom them to the curse of a hallux rigidus or metatarsalgia. Almost better is a shortened leg and a painless foot, than a perfect leg and a foot that will never again carry its owner any distance without pain.

We know and realize the value of constant pressure or tension in stretching pathological structures, but these same agencies are no less potent for evil when applied to healthy and uninjured structures, as witness for example the acute flat foot of the messenger boy or young waitress. When the baneful effects of acute sepsis, even in a distant part of the limb, are added, the evil is increased a hundredfold. Thus it comes about that the flat foot-piece made of wood, the club-foot shoe and the like, while admittedly preventing the development of foot-drop, tend when used over protracted periods in the absence of mobilization to promote rigidity and often lead to deformity. If the sole of the foot is kept absolutely flat the ankle is in a position of eversion, and there is constant pressure over the head of the fifth metatarsal. The anterior arch, after weeks, or it may be months, of pressure in the presence of sepsis, yields slowly but surely. The head of the first metatarsal is also subjected to pressure, it slowly rises and the hallux drops. The rigidus deformity is then not far off.

Remembering, then, that mobility can only be maintained and not increased by manipulation and massage in the presence of sepsis, what should be done ? In the first place flat sole-pieces for all splints should be abolished, shaped splints, preferably of plaster, taking their place or, if flat foot-pieces are used, adequate padding properly shaped should be inserted behind the heads of the metatarsals. Second, the moment actual danger to the patient's life and fear of amputation are over, every case should receive—a few minutes will suffice—a short dose of massage and mobilization daily. If it is only the toes that can be treated, still, as a prophylactic measure, the treatment is invaluable. But whenever possible, from the outset, or at least at the earliest possible moment subsequently, not only toes but metatarsals, tarsal joints, and ankle should be liberated for their daily mobilization. Moulded splints or active treatment alone are inadequate ; both are needed alike to avoid catastrophe.

So, too, if the foot is wounded, the patient should receive the fullest treatment possible, and from the earliest possible moment, for the whole of the rest of the limb. Massage alone, even of the thigh, helps to enhance the richness of the vascular supply below, the one means at our disposal of assisting recuperative power. Then as soon as it is safe to do so—long before the patient can leave his bed it may be—active exercise of hip and knee can, far more than massage, further increase the supply of blood to the limb and so promote healing and repair. At first assistance is required. This is reduced daily till free movement can be indulged in at frequent intervals during the day.

Turning next to the hand. Though the three outer metacarpals may be shot away, tubes run through from front to back, and though the whole hand be puffy and shapeless with œdema, yet, as in a recent case, the mobility of thumb and index can be maintained, wrist kept supple, and rotation secured. As mobility in each joint decreases day by day, or at least week by week, so the extent to which physico-therapy can assist restoration diminishes : every degree of movement that is lost is gone for good until active sepsis has ceased, and then months of treatment will be required to loosen joints that never need have been allowed to become stiff. If the mobility of fingers can be maintained in the case of hand injuries, how much more must this be possible in the case of injuries in more distant parts of the upper extremity !

Some surgeons realize these points and tell their patients to keep toes or fingers moving. This is good but it is not enougn. The patient must be taught to move *each* joint and usually requires assistance to carry out the full range of movement. Some even instruct their nurses to perform the movements, but this is not in the best interests of the patient. Any surgeon can extract a molar tooth ; few would claim to do it as skilfully or with only the same amount of pain as a dentist. So, too,

a nurse can move a foot or hand : she cannot do it with the knowledge and practised skill of the masseuse ; and, further, only a masseuse with special training and adaptability should be entrusted with these cases.

Let the surgeon, then, when treating a fracture remember always that he is treating a patient, and that the patient consists of other structures besides bone. Let him deal with the bone to the best of his ability and enlist all the help he can get for the treatment of other structures. In this way he will assist his own ends as well as confer the greatest possible benefit on his patients. As Lucas-Championnière preached, it is movement that is life ; while fixation and lack of movement lengthen repair and often maim, in spite of perfect restoration of the bony injury.

From the outset and even before union has begun, at the very latest when it has become ' sticky ', pure passive movements of the joints adjacent to the injury should be administered. In skilled hands there is no risk of return of deformity, or, if drainage is adequate, of lighting up sepsis. In these movements force finds no place : we are not attempting to gain mobility, only to maintain that which has not yet been lost. Safer far is it to do it while the wound is widely open than later when it is nearly closed. Between treatment, however, every care must be taken to ensure that splintage is efficiently and accurately re-applied.

Much has already been said on the treatment of joints in military orthopædic cases. A few further points require notice. Perhaps the most important concerns the treatment of knee-joints that have been opened, cleaned, and sewn up. This triumph of modern surgery is frequently rendered of no effect by after-treatment. If sepsis is present it manifests itself freely enough : if absent there can be no call for fixation. Mobilization can and should start forthwith—three to seven days may be allowed to elapse to make certain whether sepsis is present or not. If all is well by that time, mobilization can be started in safety. It is, perhaps, hardly sufficiently realized that treatment by mobilization consists of three stages, pure passive (or relaxed) movement, active movement, and assistive or resistive movement.

The passive movement is secured as it were by stealth, and consists of gaining the absolute confidence, not only of the patient, but of the patient's muscles. A careless attempt to move even a healthy and supple joint is almost always attended by involuntary assistance or resistance on the part of the muscles controlling the movement. To avoid these the support afforded to the whole limb must be secure and give assurance to the muscles that there is no danger of jolting, jarring, or of sudden change of support.

By infinitesimal changes in support, e. g. increased pressure under the knee with decreased pressure under the foot, a minute movement is performed slowly and then the process is reversed. At the first alteration of pressure no movement is secured, then two or three degrees—no more, only a faint trace of movement—so slight and so gently performed that the patient and his muscles alike fail to detect that movement has taken place. Ever slowly and gently the process is repeated, each time an extra advance—usually almost imperceptible, but sometimes it may be quite considerable. It is quite safe to proceed until the patient's muscles give warning that the limit is approaching by a faint twitching, usually felt rather than seen.

It is while performing movement of this type that surface-stroking massage finds its *métier*. Not only does the stroking soothe away a tendency to spasm, it conveys to the muscles a sense of security, and it also gives warning to the hand if spasm is impending. The instinct that warns us when the limit is being reached corresponds to that felt by the rider when a horse is becoming restive. Instantly the original position of rest is restored and the *séance* is either brought to an end or is resumed *ab initio*, if sufficient movement has not been gained. If the muscles become ' restive ' during this second attempt at an earlier stage than before, then too much is being done and the treatment must cease.

Thus, and thus only, should mobilization be administered to a recently injured joint. The positions chosen for movement vary at each joint, and combination of movement calls for careful study. These I have indicated elsewhere.[1] Study of these essentials and patient practice alone can render the masseuse competent. Ignorance of technique may well lead to disaster. As well might we entrust church embroidery to a carpet-mender, as this type of treatment to the nurse who has not been trained in the art. Safer would it be to give no treatment, although this is to jeopardize the future function of the joint.

When movement is well advanced, the patient may be asked to contract his muscles while the masseuse is restoring the last few degrees that lead to the ' rest ' position. By slow stages the patient is then trained to help through an ever-widening range of movement, till finally he is ready for pure active movement. Even now, be it noted, function of the lower limb is by no means complete. The movement may be fully restored, but there has been no attempt at weight-bearing. This again is added by imperceptible stages. It is hard to imagine anything more grotesquely unscientific than to leave a patient with an injured knee strictly at rest up to a certain point, and then to pass over all these intermediate stages at one fell swoop and tell him to get up and walk upon it. Treatment such as that outlined is free from risk and will save

[1] *Massage: Its Principles and Practice.* J. and A. Churchill.

the patient from the necessity of a far more risky treatment, namely, movement under an anæsthetic at a later date. Moreover, we are treating the patient thereby and not only his joint: we are aiding the blood supply and we are keeping his muscles in tone.

One more point must be kept in mind when treating all joints. Every movement that is possible at each joint must be performed—I have already mentioned the six movements possible at each joint in each digit. It is necessary also to remember rotation at the knee-joint, and, perhaps most important of all, antero-posterior movement at the inferior radio-ulnar joint in every position of rotation. When performing movement at the elbow the existence of the 'carrying angle' must not be overlooked.

Reference has already been made to the after-treatment of tendon suture. At operation no tendon is shortened to the fullest extent or function could not return. Therefore movement in the direction that relaxes the tendon can always be performed from the outset without laying any strain upon the suture line. For instance, if the extensors of the fingers have been sutured, some degree at least of palmar flexion of the wrist can be combined with full extension of the fingers and dorsi flexion with their flexion. By the end of the first week the earliest attempts at voluntary contraction of the flexors can be made, but the last few degrees of movement, i. e. full flexion of fingers combined with full palmar flexion of the wrist, should never be made till quite the end of the third week. By making an early start not later than three days after operation, adhesions between the tendons and the surrounding structures can be obviated or at least reduced to negligible proportions.

Tendon transplantation should invariably be followed by early mobilization, provided adequate skill in treatment is forthcoming. To hand over these cases to one who has no special training is merely to court disaster. Success depends in no small degree on two factors, the mentality of the patient and the care taken by the surgeon to avoid preventable injury to tissues surrounding the new bed of the tendons. I have seen three cases in which a transplant in the forearm has apparently so confused the patient's control over his muscles that complete functional paralysis of every muscle below the elbow has followed operation. The masseuse must know exactly what has happened, and also must have studied closely on herself the movements that are performed by the tendons that have been transplanted. She must then instruct the patient how to cause the muscle attached to each tendon to contract in turn on the sound limb. The action is studied and it is explained to the patient what movement is to be anticipated from similar action in the injured hand. The muscles are then called upon to contract in turn and the expected move-

ment is performed for the patient. As soon as the new function can be performed at will the patient is encouraged to make general use of the limb. It usually takes three weeks to teach a patient to regain the first control of his movements, but six weeks is not too long to allow for patients of low mentality.

Before and after suture of a nerve a patient can benefit very materially from treatment in the Massage Department. Before operation joints should be kept as mobile as possible. This means that, if treatment is begun soon after injury and before stiffness is established, full mobility is maintained : if a start is delayed till stiffness is established the remaining mobility can be maintained, but restoration of the full range by manipulation is problematical and can usually only be secured by intelligent combination of splintage and mobilization. Meanwhile every effort should be made to maintain the general nutrition of the limb by full exercise of all healthy muscles ; the greatest care, however, being taken to guard against over-stretching of the paralysed muscles. For instance, a patient who wears a small cock-up splint can perform very full exercises for the whole of the upper limb in spite of a musculo-spiral paralysis. When using a weight and pulley he invariably stands with his back to the apparatus, and grasps the rungs in full supination when performing ladder exercises. Only in cases of very high and extensive lesions should massage be allowed to replace active exercise.

One word of warning is necessary as to the technique of massage on paralysed muscles. The objective is to promote the onflow of lymph and blood in lymphatics and veins, which incidentally removes waste products. Then we hope to maintain nutrition by direct action on the arterial side of the circulation. This can be secured in two possible ways, first by reflex—problematical in cases of nerve lesion—and by ' toning up ' of the arterioles. The muscle in these vessels is unstriped, and therefore responds by contraction to mechanical stimulation. Every surgeon who deals with abdominal cases knows that the amount of paralytic ileus that follows operation varies in direct proportion with the amount and severity of the handling the gut has received. In other words mechanical stimulation of unstriped muscle, if carried to excess, leads to paralytic relaxation.

When we are performing massage over a paralysed muscle there is no protection from our manipulations for the arterioles in the ordinary ' tone ' of the muscles. Every movement therefore is, for all practical purposes, applied direct to the unstriped muscle in their walls. Let us beware then lest, by over-stimulation, we paralyse these vessels. Only the most gentle and delicate manipulations should be performed, and every care should be taken not to compress any structures directly between

the fingers and the underlying bone. All forms of *tapôtement,* vibrations, or frictions should be prohibited. Only the gentlest *effleurage* and ' picking up ' should be allowed. Vigorous treatment can quite readily postpone recovery indefinitely. This can be seen again and again in cases of paralysis that have received injudicious treatment, and is particularly common in infantile paralysis cases.

After operation another use can be found for massage. The formation of cicatricial tissue around the nerve trunk is inevitable. This can be kept supple and its contraction minimized. Not infrequently patients who complain of pain after operation are found to have a definite bulbous formation at the site of suture. Static nerve frictions over this bulb soon reduce its size and consistency and the pain is correspondingly relieved. Active treatment, local for the site of suture and for the paralysed muscles, general for the rest of the limb and to maintain mobility, should be begun within a few days after operation—the delay should certainly not be longer than suffices for the removal of the stitches. Particularly is this the case after hersage or similar operation. When a nerve has been sutured under tension by means of flexion or extension of a joint, no movement in the reverse direction should be performed for ten days, and complete movement had better be delayed for three weeks. Movement in the same direction, however, may with advantage be administered in its entirety from the outset. The moment there is the faintest trace of recovery, muscle re-education should be undertaken.

The treatment of contractures by massage and manipulation without the aid of splintage is unprofitable labour. They are due either to adaptive shortening of the structures which form component parts of the joints or to pathological changes in the structures passing over them. To effect restoration, active stretching is required, and the stretching of elastic fibrous tissue is a very slow and tedious process. It can be performed in the massage-room, say, for twenty minutes a day, and the structures are then left in relaxation for the rest of the twenty-four hours. Splintage, on the other hand, acts throughout the twenty-four hours with the exception only of the twenty minutes' massage, which is necessary in order to maintain mobility.

But there are cases in which splintage is inconvenient or impracticable, owing to the amount of labour involved in each adjustment of the splint. Massage and manipulation can then be given trial, and success sometimes attends the treatment. Particularly is this so when the contracture is due solely to adaptative shortening of uninjured muscle, as for instance, after amputation. In a word, contracture of uninjured tissue can be overcome by massage alone, pathological cannot within reasonable limits

of time. When using massage as a stretching agency, every care should be taken to secure relaxation of the muscles that antagonize the movement and to gain all the assistance possible from those that control it. All sudden pulls and jerks should be prohibited : the pressure exerted—and it may be very considerable—should be applied very slowly and progressively. It should be relaxed in similar manner, or much unnecessary pain will be given. Perhaps the best method is for one hand to exert the constant pressure while the other performs long, firm stroking movements, each stroke tending to assist the pressure of the first hand which, so to speak, takes up the slack thus gained by each stroke. Every effort should be made to train and strengthen the muscles which could, by their activity, counteract the deformity.

C. The Treatment of Recent Injury.

A large number of simple sprains are encountered in military practice. The part is usually placed at rest, it may or may not be splinted, lotions or fomentations are applied, and no attempt is made to maintain mobility or prevent muscular wasting. The result is pain, stiffness, and weakness that call for months of treatment to eradicate. These patients, as has been shown again and again by Lucas-Championnière and his disciples, by Robert Jones, by Bennett, Wharton Hood, and others, owe their subsequent disabilities, not to their injury, but to their treatment.

To restore the damage done by a sprain as speedily as possible, massage and mobilization are essential. The massage should aim at securing the prompt dispersion of all exudate at the site of injury. This is accomplished by local kneading and friction, and further exudation is then prevented by the application of strapping or of a compression bandage over a *very thick* pad of wool which envelops the whole circumference of the limb. If strapping is used—and it often should find place when the compression bandage has played its part—it must be applied to the surface in narrow strips, never more than an inch broad, and, when applied, it should simply lie upon the skin exerting the slightest possible, but absolutely even, pressure throughout. The mistake is often made of attempting to pull the strapping tight. This is a great error. The actual pressure exerted at the time of application should be negligible. Its function is not to compress the skin but to render it inelastic and so to secure an internal massage of all the structures underneath it whenever movement takes place. It is used chiefly at wrist and ankle. For sprains elsewhere the pad and bandage are usually preferable.

General effleurage and 'picking up' of the muscles of the whole limb should be given. Then every joint should be examined and full active

movement prescribed for all joints in the limb except the one directly injured. Thus for a foot injury, toes, knee, and hip should be exercised fully and freely at frequent intervals throughout the day : if the knee is injured, foot and ankle at least must be exercised and the hip by means of trunk exercises, while throughout the patient is instructed to keep his quadriceps constantly contracting and relaxing. Even the injured joint can usually be exercised voluntarily with advantage from the outset, though its activity is held in check by the strapping or wool. After massage, or rather during its administration, the fullest movement should be given (as a pure relaxed movement) to the injured joint, the range being limited only by the onset of pain. This rule ensures that no strain will be laid upon torn ligaments or other injured structures. Movements in the direction which, if pushed, would tend to do this are not prohibited, but must be administered with the utmost caution.

In slight cases from the start, and in more severe cases when the disappearance of fluid within the joint is apparent, function (as distinct from active movement) may be slowly restored. The support of the bandage or strapping must be reduced equally slowly. It is a fatal error to keep a case of simple synovitis of the knee at rest on a splint in bed till all the fluid has subsided and then to allow the patient to walk. Treatment by massage and mobilization should begin immediately after injury.

The treatment of old sprains in the Massage Department is usually slow and tedious. It is best that mobilization should be performed under an anæsthetic, which may have to be repeated, and the case then treated as a recent injury from the start. If, however, there is much wasting and deficient circulation, a course of massage and exercise as a preliminary to the anæsthetic is advisable.

It is impossible to summarize the treatment of fractures by mobilization and massage in a few words. The technique varies with each individual fracture, and calls for individual study.[1] The main principles can alone be stated here.

When a bone is broken, other structures are injured simultaneously. These call for treatment no less than the bone. Rigid fixation by splintage withholds from these structures the treatment by which their repair can

[1] The following books contain descriptions of the technique. The amount of detail devoted to this subject is indicated by the order given. *Traitement des fractures par le massage et la mobilisation.* By J. Lucas-Championnière. (Rueff et Cie.) *Précis* (of above). (Steinheil.) *The Treatment of Fractures by Mobilization and Massage.* By J. B. Mennell. (Macmillan & Co.) *Massage des membres.* By Dagron. (Steinheil.) *Massage in Recent Fractures, &c.* By Wm. Bennett. (Longmans, Green & Co.) *Massage: Its Principles and Practice.* By J. B. Mennell. (J. and A. Churchill.) *The Treatment of Injuries.* By Wharton Hood. (Macmillan & Co.)

be accomplished ; and, when it is relaxed, all the evils inseparable from adhesions, disuse, and atrophy have to be overcome. Recovery is then prolonged, tedious, and often painful. Moreover, fixation and absolute rest tend to diminish the vascularity of the limb, and therefore delay the repair of the bone itself.

By massage the pain of fracture can be minimized, spasm is overcome, and restoration of the alinement of the fragments is thereby facilitated. Vaso-motor disturbance is inseparable from severe injury, and by massage this can be counteracted, whereas fixation tends to confirm it. Hence massage treatment tends directly to assist the processes of repair throughout the injured region, including that of the bone.

Mobilization, skilfully administered, does not tend to disturb the position of the fragments ; but, on the other hand, where alinement is at fault it renders adjustment comparatively simple, provided that the nature of the fracture is not such as would require open operation to render restoration possible.

A limited amount of mobility at the site of fracture frequently leads to non-union when treatment by external splintage alone is used. This is owing to the poverty of circulation ; but when the circulation is good and the vaso-motor disturbance is countered by massage, then mobility of the fragments tends to assist the formation of callus. Undue mobilization leads to excessive formation.

By mobilization the joints are kept supple, adhesions are prevented from forming, and the elasticity and tone of the muscles are preserved. Thanks, too, to the early date at which active contraction of the muscles can be encouraged, their wasting is minimized. In a general word, a fractured limb treated from the outset by mobilization and massage is fit and ready to perform its function the moment union in the bone is adequate to resist the strain : treated by fixation the corresponding moment finds the patient with a stiff, swollen, and painful limb, which may require months or even years of persevering treatment to restore.

As has been already indicated, the presence of sepsis, provided drainage is adequate, is no contra-indication to skilled treatment. The moment general signs of septic infection are passed, provided drainage is adequate, treatment may be begun. Even gunshot wounds of femur can be treated in this way with most encouraging results. The treatment of septic compound fractures by mobilization is no new thing, as might be supposed from many recent papers. It found its champion in Lucas-Championnière nearly half a century ago. But it will fall into disrepute if the method is practised by those who do not attempt to study its technique. For just as the plating of a fracture calls for special surgical skill and technique, so the treatment of fractures by mobilization calls in no less degree for highly specialized experience and skill.

The treatment of recent dislocations also calls for special mention. Mobility should, as in the case of fractures, be maintained from the outset, though when the stability of the joint depends mainly upon ligaments which may have been torn, the greatest care is essential lest dislocation recur. In other dislocations, the shoulder and hip in particular, provided there is no bony injury, mobilization may proceed rapidly. In the case of the shoulder, spontaneous reduction can often be obtained under the influence of massage. When once effected, the stability of the joint depends on muscular tone. But when a joint is injured the muscles that control its movement, being supplied by the same nerves as the joint itself, undergo reflex wasting. Everything possible must be done to limit this process, and active use is the main agent at our disposal. Hence it comes about that the torn fibres of the capsule—weak and lax at best—should be ignored, and the patient should be encouraged to exercise his muscles from the outset. Provided the arm is not elevated beyond the horizontal there is less risk of dislocation recurring as the result of active movement immediately after reduction, than there is some days later if the muscles have had time, and have been allowed, to waste. Much the same applies to the hip-joint, provided the acetabulum is intact.

One exception to this rule is the elbow-joint. During dislocation, though evidence from subsequent X-ray examination may be negative, it is usual for some bony injury to occur—probably in the neighbourhood of the coronoid process. Mobilization may at first yield encouraging results, but during the second week there may be disappointment and the pain on movement may increase and mobility decrease. By the middle of the third week an extensive mass of callus may have been thrown out in front of the joint. All severe injuries of the elbow must therefore be treated circumspectly, mobilization must be administered sparingly, and the limb usually be kept completely at rest in flexion for at least two weeks. If, however, there is present a T-shaped fracture which has broken the joint surface, synovial fluid can escape from the joint and pass between the fragments. This acts as a foreign body, and therefore inhibits union and the formation of callus. In this event, and in this only, should mobilization treatment of any injury in the neighbourhood of the elbow-joint be pushed.

In the Massage Department we are often called upon to treat cases that have been mobilized under an anæsthetic for the 'breaking-down' of adhesions. This is an operation which calls for greater skill and judgement than is generally recognized. Though the views expressed may not find universal acceptance, they are based on an unusually wide experience of the practice of a very large number of surgeons.

In the first place it should always be kept in mind that forced move-

ment of a stiff joint entails serious injury to tissue, be it normal or pathological. If an adhesion within a joint is ruptured the patient suffers to greater or less degree from a traumatic arthritis. If the adhesions are extra-articular, their rupture produces a condition analogous to an ordinary sprain.

The movement of a joint to the full anatomical limit is beset with two dangers. First, it is difficult under anæsthesia to realize when the anatomical limit is reached ; and, having reached it, the smallest movement beyond this limit places undue strain upon the joint and inflicts a definite injury on healthy tissues, which amounts to a more or less severe sprain.

Then, second, if a joint has been stiff for some considerable time, there is, I think, no question that the normal structures have undergone an adaptive shortening. Hence it comes about that forced movement, which may be well within the normal anatomical limits, may be excessive for the shortened structures around the stiff joint. Full normal movement may therefore result again in a severe sprain. The last consideration is similar. When a joint has not been fully flexed for a considerable period the extensor muscles have never been stretched to their full limit during the whole of this time. Adaptive shortening has taken place, and the elastic property of the muscle, from sheer loss of function, has decreased. Full anatomical movement of flexion under these circumstances appears, from clinical signs, to do one of two things—either parts of the extensor (or its tendon) or the insertion into the periosteum is torn, or similar diffuse injury is done, within the substance of the muscle, to the elastic tissue which ramifies from the tendon to surround each group of muscle fibres or even each individual fibre. In the case of the knee-joint extensive damage to soft tissues during forcible flexion may be limited by fracture of the patella putting an end to the manipulation.

The damage it is possible to inflict during movement under an anæsthetic the nature of which we can only infer from clinical signs, appears to be realized by the bone-setter. When mobility is almost complete but painful, the single twist—not to the full anatomical limit, but only to the point at which ' something is felt or heard to click or tear '—enables him to perform his so-called ' miraculous ' cures. The real stiff joint with limited movement he restores by stages, giving several manipulations under anæsthesia, and allowing adequate time to elapse between each for complete recovery from any damage inflicted. Greater success would attend the manipulations of many surgeons if it were once realized that, because a patient cannot feel pain under an anæsthetic, they are not therefore at liberty to pull, push, and twist a limb to the full limit of their power. It is pitiable to hear the repeated story of patients with almost rigid joints—either, ' I could do so and so before the last

wrenching,' or, 'it was wrenched three times at X and seemed to get stiffer each time.'

It is essential, therefore, that the masseuse should know a good deal about a patient who has just had a joint moved under an anæsthetic, if her co-operation in the treatment is to be intelligent. She must know more or less what was the condition prior to operation, and what had led to the condition, and how long it had existed. Then she should know how much movement was performed and how extensive has been the tearing or stretching of pathological (and perhaps even of healthy) tissues. It is true that she can judge more or less by the reaction, as shown by the three cardinal points—increase of pain, increase of swelling, and decrease in the power of voluntary movement, but this pre-supposes a previous knowledge of the case.

If the surgeon has merely helped the joint over the 'dead point', massage should be general of the whole limb in order to counteract any reaction, and to relieve all tendency to spasm. Then the joint should be moved slowly throughout the range rendered possible under the anæsthetic, and the patient should be encouraged to maintain this mobility for himself by repeated voluntary contraction of his muscles at very frequent intervals. This is further encouraged by allowing the fullest use possible of the limb. The function of weight-bearing of the lower limb should not be permitted after mobilization any more readily than after an ordinary accident. Thus a patient who twists his knee, or sprains his ankle slightly, may be done up in a compression pad and bandage or in strapping, and be allowed to walk forthwith. A more severe injury curtails treatment to massage, relaxed movement, active movement under supervision through the range secured by the relaxed movement, and subsequently such active movement in bed as the application of retentive material will allow. Perhaps the use of a sliding-seat may be prescribed or other forms of exercise which do not entail bearing weight. More extensive injury still, when reaction is characterized by extensive swelling and synovitis, compels further curtailment of treatment, while the onset of sudden and marked œdema, severe subcutaneous hæmorrhage and intense pain may limit treatment to massage, relaxed movements of all uninjured joints and the gentlest possible mobilization of the injured joint through minute range. After manipulation under anæsthesia, the same *régime* holds good. No patient whose knee has been moved forcibly and who evidences an acute traumatic synovitis as the result should be allowed to walk until the fluid shows signs of absorption. So, too, it is unreasonable for a surgeon to anticipate that a masseuse will, from the start, retain the full range of movement secured under an anæsthetic, if muscles or ligaments have been stretched or torn by the manipulation, and the joint is in a condition of acute traumatic synovitis, any more

than he would expect her to do so had the patient inflicted on himself a corresponding injury as the result of an accident.

The main conclusion, then, is this. After manipulation under an anæsthetic, treatment should be conducted on the lines similar to that prescribed for severe recent injury. If reaction is slight, full mobility and use may be secured forthwith. As the intensity of the reaction increases, so treatment must be curtailed, the amount of massage given increasing in direct proportion as the amount of movement prescribed or given decreases. The aim should be to increase daily the dose of movement and to decrease that of massage; but, if the reaction is very intense, it may only be possible to effect the change so slowly that relapse to the condition prior to operation is unavoidable. Fortunately, this disastrous sequel is rare except only in cases where rigidity is complicated by recent severe sepsis. Manipulation of patients suffering from war injuries should be approached far more circumspectly than in civil practice, or disappointment is inevitable.

Little need be added about other forms of early post-operative treatment. The aim of treatment is invariably a double one, prophylactic to prevent stiffness and wasting of muscles, and curative by maintaining the best possible blood supply to the part, and the removal of extravasation. It must suffice to say that operation, from the massage point of view, must be regarded as the infliction of injury, and the case is treated accordingly. It is remarkable how slight the injury may be. For instance, an arthroplasty of wrist may be treated by mobilization and massage immediately after operation on lines identical with those that are applicable to a severe Colles's fracture; if the elbow has been reconstructed, treatment may be identical with that of severe fracture in the neighbourhood of the elbow-joint. The same precautions are called for and no alteration of technique is required. So, too, excision of a knee cartilage may be regarded as little more than a severe traumatic arthritis, and mobilization treatment may be carried out from the start. The function of weight-bearing is withheld only for a few days. Exercises without weight may be prescribed from the third or fourth day.

D. Co-operation with Splintage.

The co-operation of activities in the Massage Department with those of the surgeon is shown at its best when the latter is endeavouring to secure some curative effect by splintage, plaster, or otherwise. The masseuse's duty is both to assist the surgeon's work and to prevent the benefit he confers being counteracted by any deleterious effects of the treatment.

If a surgeon is attempting by splintage to secure flexion of the fingers,

the masseuse can assist him in two directions. First, she must do all in her power to maintain efficient circulation through the limb; and, second, she must train and exercise to the full the long flexors and lumbricales. She must endeavour also to convince the patient that constant activity of these muscles between the treatments will materially shorten the period during which he is doomed to wear his splint. But her chief duty is to secure that, while the surgeon gains flexion, the power and possibility of extension is maintained. So, too, she must undertake to see that, while the surgeon is treating the hand, no mobility is lost in other joints of the limb and that no muscular wasting is permitted.

Two further duties call for special mention. The masseuse must realize that she must either restore the exact position that had been reached before her treatment or secure an advance upon it, and she must report forthwith any decrease in mobility. It is a wise precaution to enforce that any patient who attends the Massage Department wearing a splint is inspected by one of the senior members of the staff before he goes back to the ward, in order to ensure that the splint has been correctly replaced.

As regards co-operation in the use of individual splints, a few practical points call for emphasis.

If a splint has been applied as support to a bone in a case of weak union, the surgeon must state whether the splint may be removed for treatment or not. If it is to be removed, the masseuse must pay the utmost attention to the postural treatment of the patient. For example, a patient with a poorly united humerus should be seated 'side-on' on a chair, the sound limb supported on its back, the injured limb resting against the patient's side, which thus forms an inclined plane for support. A weak clavicle must be treated recumbent, the shoulders resting on a couch, the head being placed on a very low pillow. If a fore-arm, in which both bones are broken, requires treatment before union is firm, the patient should be placed recumbent, the humerus should rest flat on the couch and the fore-arm be placed in the vertical position before the splints are removed. If the limb is splinted in full extension, this position must be maintained throughout.

When treating a fractured femur every care should be taken to avoid straining the anterior bow of the bone. If the leg bones are broken, under no circumstances should the weight of the limb be allowed to rest on the heel before union is complete. A pillow should be placed under the knee and be so arranged that the heel rests free just out of contact with the couch.

If a splint is being used to prevent undue mobility of a joint, but the surgeon still wishes the dose of mobilization to be given, similar attention must be paid to posture.

The principles which underlie the application of a splint to assist the recovery of weak or paralysed muscles must be fully appreciated. Only too often the splint devised aims at preventing all action of the antagonists. This is wrong. The enforcing of absolute rest on the whole limb cannot assist a weakened muscle to recover. It can only serve to weaken healthy muscles, and to stiffen joints. There are two principles in applying splintage to assist recovery of weak muscles. First, these muscles must be allowed freedom to act directly they have the power to do so. Thus a posterior splint applied to the fingers after injury to the ulnar nerve exemplifies a faulty principle. The splint should be anterior and leave the interossei free to act. Then, second, the antagonists should not be prevented from acting altogether, a limit only should be placed on their activities so as to prevent strain falling on the weak muscles. Thus if the shoulder is healthy but the deltoid is weak, the arm should be placed on an abduction splint. If this is worn under the clothes the patient in all probability will never use his deltoid at all throughout the day. If the splint is worn outside the clothes the muscle has liberty of movement, and there is every inducement for constant activity on its part.

When treating a case on an abduction splint the masseuse should never lower the arm to the side till instructed to do so. If movement of the gleno-humeral joint is ultimately to be restored the patient should be placed recumbent before the splint is undone. It is then the duty of the masseuse to see that mobility of the hand, wrist, radio-ulnar and elbow joints is maintained. She can then practise rotation of the shoulder and try to secure further abduction. The elbow and fore-arm rotation call for the greatest attention, as they are frequently overlooked.

The long cock-up splint as usually applied may indeed rest the extensors, but it also inhibits all movement and all muscular activity, thus leading to great loss of mobility and strength. Far better is it to keep the metacarpo-phalangeal joints a trifle flexed on the splint and the inter-phalangeal joints free to extend. Then as soon as recovery is starting, the long extensors of fingers are free to act. The fingers should never be fixed to the splint in cases of musculo-spiral paralysis. So too it is a mistake to bandage the whole of the fore-arm portion of the splint into fixed position. A certain amount of play should be allowed at its upper end, so that the patient can secure some activity, as the result of contraction of the muscles, as soon as recovery has started. Nothing is so discouraging to muscular activity as unproductive labour. One more practical point should always be observed when applying a cock-up splint. The adhesive strapping or bandage should never pass transversely across the back of the wrist. This obstructs the venous return and leads to chronic œdema, and tends to stiffen all the finger-joints. The crossing should always be diagonal.

When treating a patient who is wearing a cock-up splint, the masseuse should invariably see that movement at shoulder and at elbow, and that fore-arm rotation, are perfect. Throughout treatment the wrist should never be lowered beyond the position of the hand in writing. All movements at the wrist should be given with this limitation, and particularly ulnar and radial deviation. A certain amount of rotatory movement is also possible at the radio-carpal joint. Every movement at all the finger-joints should be secured as far as possible while the wrist is in *full* dorsiflexion. There are many exercises, particularly with the weight and pulley, that can be performed with advantage by a patient while wearing a short cock-up splint.

It is a bad though common practice to bandage a foot firmly into a plaster splint or club-foot shoe in cases of foot-drop. Far better is it whenever possible to use a splint with a foot-piece that can dorsi-flex, but not plantar-flex. If a rigid splint must be worn, then the toes should be allowed full play in dorsiflexion, and the bandages should be applied only so as to enforce that the splint shall remain in position, while a certain amount of freedom of action—limited, of course, but none the less valuable—is allowed to the ankle. The patient, in other words, should be able to wriggle his foot and ankle about. This is the principle which first induced me to experiment with a posterior plaster splint, applied at night to the back of the hand and fingers, for the use of patients who are unable to ' make a proper fist '. The flexors are left free to act, and by their action, almost involuntary, they are constantly tending by their own endeavour to increase flexion and overcome the stiffness. This is the ideal way of dealing with all forms of stiffness.

When treating cases of foot-drop the masseuse should never allow any strain on the extensors, and it is her duty to maintain mobility of the ankle and of all foot joints. This is best done by treating the patient prone with the leg at right angles to the couch.

When applying tension to a stiff joint by splintage, e. g. finger-tapes or a cuff and collar, it is not always wise to trust a patient implicitly. If doubt arises, it is well to mark the tapes or the suspension at the points at which they are tied. It is then plain at the patient's next visit whether or no the tension has slipped or been relaxed. A rotation plaster can be marked on the plaster. The masseuse must realize that it is her duty to take great care, in readjusting these contrivances, that the tension at the end of treatment is at least as great as at the beginning.

In all these cases the masseuse should endeavour to exercise to the full the muscles which, by their activity, would assist the movement the splintage is designed to encourage. She must also see that mobility in the opposite direction is maintained, as also that of all joints in the limb not directly affected by the apparatus.

When applying a back splint to assist in the straightening of knee or elbow it is often a mistake to try to get full extension at once. The splint is fixed on firmly with the first layer of bandage so that it shall not slip. A second layer can then often be drawn more tightly, thus gaining further extension, and this process is repeated till no more tension can be borne. It may be expensive in material, but the result is worthy of the expenditure.

Every endeavour must be made by the masseuse to maintain flexion and to strengthen the extensors. Incidentally, this teaches the flexors to relax. All other joints in the limb must be examined and kept freely mobile.

E. The Re-education of Muscle.

The re-education of muscle entails the consideration of two factors, viz. muscle rest and muscle action. An intelligent combination of both is essential if recovery is to be hastened to the full extent. A muscle that is weak can never recover its power if it is subjected to a constant strain. This fact is recognized when treating a paralysis of deltoid or a case of wrist or foot drop ; its recognition is no less essential when the intrinsic muscles of the hand are similarly affected.

The principle which underlies splintage for muscle rest has already been stated ; our aim should be, not to inhibit, but to limit the action of the antagonists, while leaving the weakened muscle free to act as soon as it has power to do so.

Muscle re-education entails clear understanding of the main action of each individual muscle. Unfortunately, anatomy text-books fail to give us a clear guide, and the only book which has been written with the one object of attributing one definite action to each individual muscle is *The Action of Muscles* by Colin Mackenzie.[1] This author claims one definite action for each muscle and inclines to negative the proposition, hitherto accepted, that many muscles may perform a double function. This view will not be universally concurred in, but it gives the right line to follow when attempting muscle re-education. Not only so, it furnishes a bridge across the gap between the time when passive movement alone is possible and the ordinary remedial exercises can be performed.

The whole secret of muscle re-education may be summed up in a sentence. The antagonists must be taught to relax and the weakened muscle must be provided with work which is not above its strength to perform. To take concrete examples, it is useless telling a patient to raise his foot when the dorsi-flexors are too weak to do so. They simply fail to contract. Place the patient prone on his face, bend the knee to a right angle and tell the patient to plantar-flex his foot. Then call upon

[1] Published by H. K. Lewis & Co. Ltd., 1918.

him to dorsi-flex, and, if there is any voluntary power whatever in the extensors, they will contract. If there is no power the antagonists will relax and the foot fall into dorsiflexion owing to gravity. This falling proves at least that there is no opposition to contraction of the extensors. As soon as the power of contraction is restored in this position the patient is made to perform the exercise on his side, then on his back, and finally, while sitting with the foot dependent.

So, too, re-education of a case of musculo-spiral paralysis starts with the hand in full supination; as soon as the extensors of the wrist can contract in this position, pronation is added till the mid-position is reached, the last stage being accomplished when they can contract in full pronation.

A very important point is gained by training on these lines. The joint-sense—which is largely responsible for co-ordination—is maintained or re-educated.

Early rotation of the fore-arm is trained with the patient recumbent, the arm resting on the couch and the fore-arm vertical. As recovery advances the fore-arm is lowered and the back raised till the action can be performed sitting up with the fore-arm at a right angle. Thereafter the muscles are trained to act through every stage of flexion, and then of extension, of the elbow. A weak elbow may be trained in the same way, or, better still, the patient sits on a low stool, and the whole extremity rests on a table which supports it in the horizontal plane. A weak deltoid should always be trained in the first instance in the recumbent position. The back is slowly elevated as recovery takes place.

Re-education of the grip is best done by training the flexors sublimis and profundus to contract as if gripping a golf club, the metacarpo-phalangeal joints being extended. The lumbricales are trained by flexing these joints while the inter-phalangeal joints are kept extended. Training starts in pronation and ends in supination.

The long extensors of the fingers—which, according to Mackenzie, act only on the metacarpo-phalangeal joints—are trained by flexing and extending these joints while the inter-phalangeal joints are kept flexed, and the interossei are dealt with by alternately flexing and extending the inter-phalangeal joints, while the metacarpo-phalangeal joints are kept fully flexed. Both these actions are trained first in supination and finally in pronation. The lateral movement of the phalanges is best taught by fixing posterior splints lightly over the dorsum of the fingers. The hand is then placed flat on a smooth board and abduction and adduction are practised.

A weak quadriceps is trained first with the patient prone, then with him on his side, and finally when recumbent. As soon as he can tighten the muscle fully in the recumbent position, he is taught to do so with his

heel over the edge of the couch, then more and more of the leg is allowed to hang over the end, till finally he is able to raise the leg from the perpendicular to the horizontal. When training the flexors the positions are reversed. The positions for training the leg muscles have been indicated.

Training performed thus is liable to be dull and uninteresting, particularly when we remember that the exercises should be performed at frequent intervals throughout the day. The man who wishes to get well will practise four or even six times a day for a quarter of an hour.

As an alleviation from monotony it is often possible to substitute exercises with the weight and pulley. One example alone must suffice. A weak deltoid is trained by standing the patient under an overhead pulley and attaching a considerable weight. When the adductors relax the weight elevates the limb into abduction and the adductors pull it down again. By reducing the weight, more and more work is given to the abductors till, finally, when no weight is attached a full free-standing movement of abduction is performed against gravity. Throughout it must be remembered that it is as important to teach strong muscles to relax as it is to teach weak muscles to contract.

F. Re-education of Function and Co-ordination.

If there is one error more glaring than all others amongst those who practise orthopædics it is this : they are liable to take too much credit to themselves alike for success and for failure. It is all too common to hear a surgeon say he has 'cured' a patient and to hear a masseuse make a similar claim. Both are usually in error, for it is the patient who has cured himself. The surgeon can only make cure possible. The masseuse can show the patient how, and can even help him, to cure himself, but the one thing essential to recovery is voluntary effort on the part of the patient. Without this the work of the surgeon is useless, and that of the masseuse futile.

It is only when this great principle is appreciated by all concerned that orthopædic work is truly successful. It is pitiable to see a patient come for treatment fully prepared to believe that what is done for him will cure him. So long as this belief lasts he will and can make no perceptible improvement. Small wonder then that so many lose heart. At the very outset of treatment in the Massage Department each patient should be made clearly to understand that his recovery depends on himself, not on the efforts of the masseuse, and that all she can do for him is to show him how to get well and to assist him in the process.

Now every patient who has suffered injury to a limb suffers to a greater or less extent from muscle wasting. This may be due to direct injury, to reflex, to disuse, to lack of innervation or blood supply, or

possibly to toxic influences. But, whatever the cause, some muscles in the limb will be found more wasted than others ; and not only has a wasted muscle less strength, but it also responds more slowly to impulses —it has a longer latent period—than its less wasted fellows. It is impossible then that co-ordination in movement should be faultless, and, if we wish to help a patient to restore his limb, the first thing to do is to tackle the co-ordination.

Wherever possible, the plan of action should be modelled on Frenkel's lines, co-ordination at the proximal joints being secured before any attempt is made to train those more distally situated.

Every patient with an injured limb should therefore be taught, from the earliest possible moment, full co-ordination exercises. The usual sequence in the lower limb is plain leg-swinging, advancing till the patient is able to perform a full bicycling movement in the air. Then he is slowly trained till he can practise a ' jog-trot ' while sitting on a chair. In this way two things can be accomplished by assiduous practice : the masseuse, be it noted, can only teach, it is the patient who does the work. The strong muscles tone down, as it were, the strength of their activities to co-ordinate with those of the weaker, while the weaker strive to increase the power of their contraction to match that of the stronger. So, too, the strong muscles learn to lengthen their latent period so as to approach more closely that of the weaker, while the latter in turn learn to respond more readily. Long before a patient can bear weight on his limb he should have all possible movement at each joint perfectly co-ordinated from hip to terminal interphalangeal joints.

In the upper limb, co-ordination should be maintained to the utmost limit from the outset of treatment. A patient cannot do this of himself ; its importance cannot be recognized by the light of nature alone, and the gradation from simple to combined and more complicated co-ordination is an art which calls for close study.

But it is constant practice alone that can restore function, and this is seen in a number of different ways. Two common examples must suffice. A patient with a rigid hand usually regains power of movement and co-ordination more rapidly in his thumb than in any other digit. It s the most useful, and therefore the most used, and use is the best restorer of function and co-ordination. Then again a patient who lacks rotation of the fore-arm frequently has a feeble grip. As soon as rotation is restored power returns ' miraculously ' to his hand. The ' miracle ' is nothing more or less than restoration of ability to use more freely.

It is perhaps too little realized how dependent we are for co-ordination on joint-sense, and, as with most things in the body, lack of use tends to degeneration. It is all-important therefore from the outset of treat-

ment that every effort should be made to keep this sense at its highest pitch. This can only be accomplished by movement. The earlier mobilization can be started in treatment the better for the patient. Moreover, nothing can inhibit co-ordination more thoroughly than pain in a joint, as witness for instance the 'weak knee' of the patient who has some minute adhesion within the joint. This is broken down and the knee is strong and well once more. Yet no change has taken place in the musculature: only the inhibitory discomfort has vanished. Hence it comes about that forceful manipulation that leads to persistent pain inhibits restoration of function and co-ordination. This does not mean that a patient cannot be taught to perform a movement in spite of pain. He can, and usually must, learn to do so, and thereafter constant practice and nothing else will succeed in attaining the end in view. But by pure voluntary effort it is wellnigh impossible, at any rate it is very unusual, to cause pain of such severity that it will persist for any considerable length of time. The patient is therefore ready and able to repeat the attempted movement almost immediately. If, on the other hand, forceful movement is performed at a joint, it is useless to attempt re-education till the reaction has passed off. Therefore, whenever force is called for, it is wiser to treat the patient twice daily, performing his movement at one sitting and training him at the other. The only essential is that the reaction shall not be so intense that pain persists throughout the interval. If it does, it is usually best to sacrifice the dose of mobilization in favour of the increased voluntary effort that can be secured thereby.

When attempting to restore function, therefore, the first thing to be done is to impress upon the patient that he has got to cure himself or remain uncurable—not incurable. No one can do it for him Training in volitional effort is not infrequently necessary. Then he must realize that what he does under the supervision of his masseuse is only a small part of his 'cure'; he must endeavour all day alternately to rest and to work his injured limb as he is taught to do. Gradual reduction of rest is an essential, as fatigue is inimical to success. Finally, it should be the masseuse's aim day by day to set her patient a task to perform, infinitesimal it may be, but none the less real, more strenuous than the most successful effort of the day before. Accomplishment to-day of the unattainable yesterday is a great incentive to perseverance.

One last point, but perhaps the most important. The masseuse must realize that it is not in the best interests of her patient that either he or she should keep their attention glued to the injured limb. Double arm and double leg work often help to restore function far better than if the injured limb alone is treated; while, whenever possible, it is well to combine the use of all four limbs when attempting to restore function

and co-ordination in any one of them. This is the secret of Colonel H. E. Deane's success in his gymnasium at the War Hospital, Croydon.[1] His teaching is sound. Teach a man who cannot grip well with one hand to climb a rope and he will soon recover his strength; shoulder movement and co-ordination can best be trained by swinging, not one, but two Indian clubs. So, too, the man with the stiff knee may improve enormously with exercise on the parallel bars.

Perhaps the best example of conferring benefit on an injured limb by ostentatiously encouraging the use of its fellow is found in the use of the weight and pulley in leg re-education. The leg on which the patient stands is doing at least as hard work as that which is engaged in raising or lowering the weights; and, in addition, it is called upon to perform very definite balance work. Hence it is a mistake to attach only the injured leg to the apparatus: even more important it may be to reverse the position.

G. Elementary Class Work.

Reference has already been made to the psychological value of class work over that of individual effort. It has this advantage, too, that it is often more easy to correct a fault in oneself by the study of those in others. Even in the earliest stages it is often possible to promote a sense of emulation and to make the most out of the sporting or competitive instinct. Monotony and tedium can also be avoided to a large extent by change from one class to another, thus securing either change of companions, of instruction, or of both.

In practice it is not uncommon to find that a large amount of work done in these classes is not true class work, but rather individual training under supervision. Certain definite co-ordination and general exercises are done together, then each patient is set to work out his own particular salvation.

It is a little hard to lay down hard and fast rules as to when a man should pass on to the gymnasium, but a few examples may serve as a guide. A patient with a weak knee from any cause may be moved on when he can walk a mile without resting and without causing any recurrence of synovitis. A patient with an injured hand should be promoted as soon as he can manage 'arms bend and stretch' in the high curtsy sitting position when using both hands.

Some patients, there are not many, should complete their hospital training in these classes. Men who have had severe head, chest, or abdominal injuries are not infrequently unsuitable for the games part

[1] *Gymnastic Treatment for Joint and Muscle Disabilities.* By H. E. Deane. Oxford Medical Publications, 1918.

of the Gymnasium training; and the neurasthenic, particularly the insomnia type—I am not referring to the hysterical subject—is rarely suitable to pass on. Yet without the elementary class work, none of these patients could possibly receive the treatment and training which will most rapidly restore them to usefulness.

Just as massage is the stepping-stone by which the patient passes to relaxed movement, and this serves in turn as the 'open sesame' of active movement, so muscle-training is a further step in restoration of function which cannot be reached in one fell swoop. Something should bridge the gap, and the one thing that can do it is elementary class work.

Take, for instance, the patient who has had a septic wound of his femur. Two months before he is allowed to discard his walking calliper he should be fit to begin to place ever-increasing weight on his unsupported limb. He should be fit to be able to perform many simple exercises under supervision a month later, if he is to be trusted to move freely 'on his own' in four weeks' time. These patients are not fit for the Gymnasium; their place is to be found in the elementary class. Here, too, *par excellence*, combined training in function and volition can be carried on in its earliest stages, joint-sense can be maintained or restored, co-ordination can be re-established, and the development of faulty action checked. Far easier is it to prevent 'tricks' from developing than to eradicate them when once established.

One other invaluable part can be played by the work done in these classes. Certain patients are doomed never to recover certain movements or certain actions. In order to restore the fullest possible use to the limbs thus handicapped, the patient must be taught to develop other activities to compensate for those that have been lost. The most common case of this type is the patient with the ankylosed shoulder. Without training it is impossible that he should learn how to use his limb to the best advantage or how to strengthen to their full the muscles that must henceforth serve him in 'shoulder' movements. It is of great assistance to be able to show him another patient in the same class who is doing something he cannot do, and then to show how closely he can approximate by entirely different muscle action. So, too, as in a recent case, the patient with a permanently paralysed deltoid can be taught to abduct the shoulder fully by giving a slight flick to his elbow preparatory to performing the rest of the movement with the supra-spinatus and the clavicular part of the great pectoral. Not infrequently a patient with irretrievably damaged fore-arm extensors can be restored to a very high degree of usefulness by training him to take advantage of the insufficiency of the extensors, and use this as a means of securing a grip in dorsiflexion by simply contracting the long flexors of the fingers Similarly he lets go by relaxing his flexors, the wrist drops and auto-

matically the fingers extend. ' Tricks ' of this type are frequently all-important to recovery of function. They can best be taught by means of individual instruction, but, once learnt, they are best developed in class work, the class being very small and under the closest supervision.

Not only training, experience, and knowledge, but also resourcefulness and tact are called for in their highest development if these classes are to be successful. It is worse than useless to entrust their care to one who is only a masseuse. The trained gymnast is essential.

H. The Treatment of Deformities.

Few points call for special mention under this heading. There is little to be added to what can be learnt from many of the published works on massage and remedial gymnastics. A few details selected at random may not be out of place.

First, the soldier's foot is often a source of heart-breaking failure. Do what one may, many seem to be seriously incapacitated and to fail to improve. It is to be hoped that return to more congenial and lucrative employment in civil life will prove to be a panacea for ' painful feet '.

I have been called upon to treat patients who have had every operation surgical ingenuity can devise for the correction of hallux rigidus, valgus, and flexus. Experience shows that the more simple the operation, the better for the patient, but that the one essential in all cases is early mobilization.

The result of operation for hammer-toes is almost invariably better if ankylosis is secured.

It is impossible to stretch a shortened tendo Achillis by massage, or even shortened extensor tendons of the toes. The rapidity with which the latter join up after tenotomy is amazing, and nothing seems to prevent it. It follows then that patients with claw-foot improve little, if at all, as the result of massage. Much, however, can be accomplished, and many a cripple could be cured, if only he would practise assiduously the art of picking up with his toes first a marble, then a golf-ball, and finally a tennis-ball. Cure entails perseverance and practice to an extent that is not very frequently forthcoming. After operation patients can be re-educated in walking and mobility can be maintained.

If the plantar fascia or the tendo Achillis has been divided there is often effusion at the site of operation. This has generally organized into fibrous tissue by the time the patient reaches the Massage Department, and the resulting ' bulb ' is often extremely sensitive. Deep frictions or the persistent use of a vibrator will alone eradicate the sensitiveness which may greatly inhibit restoration of function.

Flat feet usually do better if the heel alone is wedged and not the

sole as well. If, however, the deformity is extreme and the longitudinal arch is obliterated, it is usually well to wedge the sole in addition.

It would seem that metatarsalgia can be alleviated only by restoring mobility to the inter-metatarsal and tarso-metatarsal joints. The lumbricals and adductor transversus also require training. This can best be accomplished by learning to pick up various objects with the toes as already described. Support behind the heads of the bones is essential, if the metatarsal bar on the sole of the boot proves insufficient.

Experience would tend to show that osteo-arthritis in the joints of the foot is a very disabling condition. The more the joints are loosened, the worse is the pain. Ankylosis seems to offer the only chance of relief. I know one patient who had a most perfect reconstruction of ankle performed after an old Pott's fracture with outward dislocation. He is now begging to have his foot amputated in spite of perfect shape and good movement.

It is wellnigh impossible to train a patient to walk properly who has any marked backward bowing of his tibia, and only the very slightest degrees of genu recurvatum are compatible with reasonably good function unless a knee-cage is worn.

Contrary to expectation, it has proved to be possible to reduce the element of limping to surprisingly small limits in patients who have ankylosis at any of the three main joints of the lower limb. Careful training is essential. It is also certain that, if the ankle is fixed, the patient does better if his foot is very slightly dorsi-flexed or at a dead right angle, than if it is kept in any degree of plantar-flexion, however slight. Re-education is also more simple in a patient with an ankylosed knee if there is a slight anterior bow. A posterior convexity, however slight, is a great handicap.

It is surprising how much a patient can lose of scapula or clavicle or both, and yet regain function as the result of careful training.

At the shoulder-joint, if any rotation can be kept, it is invaluable. If ankylosis has taken place with the arm hanging at the side and not abducted, training is wellnigh useless. Osteotomy is essential.

It is wonderful how much can sometimes be attained by training an elbow that is apparently useless. Early mobilization is full of danger in inexperienced hands: efficiently performed it may be invaluable. The cardinal laws of treatment of recent injury must be adhered to most closely or disaster is inevitable. A flail elbow is rarely beyond hope, and may regain function which was apparently lost irretrievably. It requires long and patient training, but at best the limb cannot be very strong.

It is probably not sufficiently realized—certainly it is not by the average masseuse—to what a large extent loss of rotation of the fore-arm

is due to spontaneous partial subluxation backwards of the head of the ulna. Even when the condition has not advanced to this stage, the joint frequently gets ' sticky ', and also the joints between the ulna, the fibro-cartilage, and the carpus. These should always receive due attention whenever there is any restriction of rotation.

A gap or non-union in the lower part of the shaft of the ulna is often a source of great benefit to the patient. Excellent rotation can be secured by this means, and even resection of a small piece of the bone in this position can yield admirable results.

Re-education of a strong grip is impossible unless the wrist can be extended at least to the position of the hand in writing. Re-education after operation for wrist-drop by tendon transplantation, and in cases of insufficiency of the extensors, has been dealt with (see pp. 536 and 555).

If the metacarpo-phalangeal joint of any of the fingers is ankylosed, the straight position is a serious drawback. Forty degrees of flexion is the ideal. Fixed in the straight position, training yields good results only if the index or little finger is involved ; but insuperable difficulties lie in the way if either of the other two fingers is affected in this way. If the inter-phalangeal joints are restricted in movement, the best function is secured if they are fixed in semi-flexion. A thumb that is fixed in any position save that of full opposition is wellnigh useless. No amount of training can render it otherwise.

Deformities of the type of Ischæmic or Dupuytren's contracture or of contracture produced by ulnar paralysis, should never be treated by massage and manipulation alone. Co-operation with splintage is essential. Massage should never be given to cases of hysterical contracture for the reasons already given (see p. 520), but whenever reflex contracture is due to psychical causes which rest on a definite physical basis the manipulations of massage frequently serve as a valuable adjuvant to physical training. So, too, contracture that is due to spasm or adaptive shortening of healthy muscle, be the muscle unduly strong from spasm or weakened from disuse, can frequently be overcome by training the antagonists to do their work more ably. The most difficult contractures of this type to overcome are flexion deformities of knee or elbow. The former is most frequently encountered after severe wounds over the back of the lower part of the thigh which have healed slowly by granulation, or in cases of fracture of the femur which have been treated by calliper extension. The failure to apply prophylactic mobilization so as to maintain extension through its full range is fraught with danger of subsequent failure of function.

THE LING SYSTEM OF EXERCISES

BY

Surgeon-Commander G. Murray Levick, R.N.

THE LING SYSTEM OF EXERCISES

ALTHOUGH the following pages wiil be devoted to the subject of artificial exercise, they cannot be begun better than by the quoting of a few lines of another writer, containing a truth which should be kept in mind by all who study or practise physical training, and, I think, a mistake which is no less important.

> Athletes and the trainers of men and animals for sport have done much for the practical study of the physiology of muscular work. The practice of training is even at the present time ahead of the theory, and each year physiological investigations show the value of the methods introduced by athletes. Experience has been the guide of athletes, and this experience is the result of numerous physiological experiments upon a large number of men.[1]

This is certainly true, and it will be a great mistake if we fail to avail ourselves of this athletic experience gained during recent years of strenuous competition. This writer, however, goes on to say that the diversity and gradation of the muscular exercise involved in the numerous forms of sport render it suitable for all men, young or old, strong or weak: that in these . . . sport is far superior to physical drill and gymnastic exercises. In this I think he is quite at fault. It is this very diversity and gradation of muscular exercise that can be so well controlled in the gymnasium, if only it is done in a systematic and scientific manner.

There is a great danger, however, that the delicate adjustments of muscular movement which have been naturally evolved in man, may be spoilt as the result of ill-arranged artificial exercises, and it is this that has caused the gymnasium to fall into disrepute.

The principles laid down here will be those embodied in the Ling system of physical training, because they appear from all points of view to be good. In theory they are beyond criticism, while their practical results are admirable.

Unfortunately, in this country, the great majority of so-called Swedish gymnasia have introduced departures, and it is very rarely that we see Swedish training properly applied.

Tables. The exercises are arranged in the form of tables, each of which consists of a complete set bringing into action all the muscle groups of the body. The exercises in each table are ' balanced ', which means that each is of an equal degree of advancement, so that opposing groups are developed proportionately. For instance, a strong ' abdominal '

[1] M. S. Pembrey, in *Further Advances in Physiology*. Edited by Leonard Hill.

does not follow a weak 'dorsal' exercise, and lateral exercises are equal for both sides.

The balancing of these tables is of great importance, and will be explained later. Should they be out of balance, evil results are certain to follow. In dealing with this as with other matters connected with set exercises, it should be borne in mind that though small details may seem too trivial to matter, their constant repetition day after day in the gymnasium make them of real importance, and quite small variations make a big difference in the long run.

Muscle Stretching. Every muscle that is contracted in exercise should afterwards not only be completely relaxed, but should be *stretched to the fullest extent of its natural position.*

This is an important thing: without it ease of movement will be lost as a result of gymnastic training, a condition that can be seen by looking at most men who have worked extensively in an English gymnasium.

Co-ordination and Symmetrical Development. Perfect co-ordination being one of the great aims of physical training, exercises should all be taught so that they are accomplished with the least possible effort without exception. Needless effort should never be expended on a movement with the idea of developing the muscles. If more effort is desired, a harder exercise should be set, i. e. one that cannot possibly be done without increased effort.

To secure this ease of movement men should be taught to use only those muscles that are actually helpful in the movement; all those that oppose it should be as quiescent as possible. The accomplishment of this principle is to be noted in the grace and apparent lack of effort displayed by an athlete of the first class, and with careful observation it will be seen to underlie the great beauty of movement in a pacing greyhound or leaping deer.

Perfect co-ordination, applied to movements of a complex nature that are new to us, is rarely acquired by the light of nature, and can only be attained as a result of careful practice under intelligent instruction.

As an example we can take rowing. To watch an untaught crew rowing in accordance with their natural instincts is a depressing sight, and their boat makes poor progress. On the other hand, a crew that has been coached by a man of intelligence and knowledge will leave the untaught far behind, and they present one of the most pleasing spectacles it is possible to see. It should be noted here, because the matter is of importance, that it is the experience of coaches in rowing, that men who have rowed untaught for any length of time are seriously handicapped, and it is often an impossibility ever to turn them into useful oarsmen. This is the result chiefly of the nervous influence of their former training, and partly to the misapplication of their muscles, so that they have been

incorrectly developed. This fault will almost certainly be an over-development and shortening of the flexors. The outstretching effect of the Swedish system particularly overcomes this tendency.

Nature, in fact, like the gymnastic instructor, can go astray in these difficult matters.

Turning again to artificial exercises, it should be borne in mind that many a youth who would have made a first-rate athlete has been condemned to mediocrity for the rest of his life by a few months of misapplied exercises in a gymnasium,[1] and that in re-education we are dealing with those who have once more become beginners.

In hospitals, when patients who have been in bed on splints for many months are allowed to get up and hobble about with sticks, the weakened intrinsic and extrinsic muscles of the feet do not perform their function properly, so that the men get into a bad habit in walking, and I have seen patients with various degrees of flat foot which I believe to have been acquired in this way.

When exercises are well balanced they may be given to an advanced degree. If a visit is paid to a championship athletic meeting, it will be noticed that the majority of successful sprinters are men of extensive muscular development, which shows plainly that strength and quickness of movement not only go hand in hand, but that powerful muscles are a great advantage on a frame big enough to carry them.

In the Amateur Athletic Championship Meeting at Stamford Bridge in 1899 a Dutch South African ran in the 440 yards race, and I used to watch him training. He was one of the most powerful men I have seen, his physical development being remarkable.

He did not win, but his time was well inside that which entitled him to a standard championship medal. It is well to keep these examples in mind, and not to tackle the subject of physical training with the idea that strength will make a man slow and ungainly if properly developed. The important thing is to produce vigour and agility, and allow the muscles to develop themselves along these lines.

It should be an axiom, however, that muscles developed out of proportion to their future requirements are certain to become ill-toned and flabby, and this leads the over-developed man to become debilitated of body and phlegmatic of mind.

Two points should be insisted on by those in charge of gymnasia : correctness of detail in performance of exercises, and smartness. I put correctness of detail first, because it is of first importance. In the 'arms bend' position, for instance, if the elbows are allowed to fall back and

[1] Confirmation of this statement will be found on looking into the athletic records of boys who have taken part in the public schools gymnastic competitions at Aldershot.

the hands forward, the most important 'heaving' muscles will not be exercised at all, and the same applies to the muscles in the dorsal exercises if the pelvis is allowed to come forward. Imagine then the result of putting a class in charge of a drill-sergeant with a cursory knowledge of Swedish drill, who is bent on the spectacular effect of a smart class drilling in unison.

Smartness, however, comes second only to correctness of detail, and there is no doubt that the mental alertness acquired in the quick response to words of command in class has a strong physiological effect, and the nervous influences called up in this way react upon the general bodily health.

Allusion has already been made to the principle of teaching a class to use only those muscles needed for each movement, and to relax the opposing groups as fully as possible.

To attain this, almost all exercises which do not entail a handhold should be performed with the forearm and hand relaxed. The reason for this necessity is that from our infancy when we pulled our baby brother's hair, we have been accustomed to close our fists only in performing acts of violence. In hauling in a rope or pulling a plant up by the roots, we set all our muscles hard in bracing ourselves for the effort. To go further back still, the young of monkeys and primitive man have held on by the pubic and axillary hairs of their parents when they have fled from danger. It is found that an infant, immediately it is born, can hang on to a horizontal bar, supporting its whole weight with its clenched hands, for a space of two minutes.

It is difficult to teach a young boxer to strike quick blows with his fist clenched. When his fists are closed as they should be, he puts too much extrinsic effort into it.

When the class is performing quick movements entailing sudden effort, it is therefore very much better to make them keep their hands open, as their primitive instinct is very hard to eradicate, and it is difficult enough to keep their attention on quickness and correctness of detail without this added factor. *The difficulty is always to keep the flexor groups relaxed in quick or violent extension movements.* It is failure here that causes the over-development and shortening of these muscles. The attention of instructors must be kept on this point at all times.

The fact is, it is the nervous control of the muscle that needs our attention generally rather than the muscle itself. Vigorous stimulus can best be attained by quick movements.

Of late years, long-distance runners have discovered this, perhaps without knowing why. In training for a mile race, a really first-class runner does most of the training by what is called 'running from a mark'.

Always, when possible, in company with other runners, he trots up

to a line drawn across the cinder track, and reaching it, he puts every ounce of effort he can summon into a sprint of a few yards to the finish, in competition with his companions.

This is repeated time after time each day. After this he runs say a quarter of a mile 'well within himself', i. e. about three-quarter speed, and occasionally half or three-quarters of a mile, always faster than he will run in the full mile, but he *very rarely runs a mile.*

We can see why this method of training has succeeded so well by which modern runners of mediocrity have equalled the finest performances of fifty years ago, and the first-class athletes left them far behind.

It is the training of nerve impulse that has accomplished this change. I have gone into this matter at some length because in the re-education of the disabled, we can benefit by using the methods of many generations of athletes who have learnt by practical experiment many things that we should have taught them long ago.

For the same reason that continual running at a slow speed makes a man lose the power to run quickly, so a preponderance of slow gymnastic exercises takes the life out of his movements and makes him habitually slow. This is quite a thing apart from muscular development. The effect is psychological, and is referred to in a vague manner by athletes as 'guts'. It is worth remarking here that it is the experience of rowing coaches that on, for instance, the Henley course, if a crew starts a full course at 40, and drops to say 34, they can row 40 at the finish, whereas if they start at 34, it is almost impossible for them to 'wind up' to 40 at the end of the race.

In the Swedish schools the work is always begun with a few quick drill movements in class, to fix the attention on the instructor and procure a spirit of alertness, and quick light movements should invariably terminate the exercises.

A complete 'table' is one that is made up of the following exercises for which there is a definite order of arrangement:

A. Introductory.
B. Middle.
  Group Exercises:
    Leg.
    Span bend.
    Heave.
    Balance.
    Dorsal.
    Abdominal.
    Lateral.
    Marching and running.
    Jumping, &c.
C. Finishing.

Introductory Exercises form a complete table in themselves, as they consist of a series of light rapid movements, involving in turn all the

muscle groups of the body (see specimen table). They are given with the following objects: (1) To secure, in an easy manner, a correct position in each group-exercise, which will be repeated in a harder form in the middle table; (2) to instil into the class a spirit of alertness, brisk response, and easy carriage: it is well, therefore, to precede the introductory exercises by a few quick drill movements to fix attention on the instructor and give him a hold upon the class at the start; (3) to increase the circulation in the muscles, dilate the peripheral arteries, promote lymphatic and venous return, reducing resistance to the heart's action, and so generally to tune up the body as a whole for the harder work to come.

All the exercises in this table should be gone through smoothly, following one on another without pause.

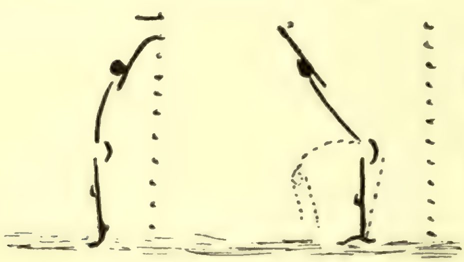
Leg Exercises. For the muscles of the hip and lower limb. The easier exercises of this group are used as deflective exercises. By increasing the blood flow in the large muscles involved, they materially relieve the resistance to the heart's action immediately after severe exercise. Thus a class should never be kept standing still immediately after great effort without first doing a deflective exercise.

The tendency usually is to under-do the exercises of this group, so that the trunk is disproportionately developed.

Span-bend Exercises. These exercises produce the most outstretching position of all. They are unique to the Swedish system; they have been much criticized, but have survived this. They are very valuable.

In effect they are chiefly a dorsal exercise, but their stretching action falls with great strength upon the abdominal and intercostal muscles. The following diagrams explain the action of these exercises in a simple manner. On the word 'heels raise', the hips must not be allowed to come forward, otherwise the dorsal spine is not bent.

After the span-bending exercise the trunk should always be bent forward and downward so as to stretch the contracted dorsal muscles and contract the outstretched abdominal muscles.



Span bend followed always by *trunk bending* forward and downward. (To stretch the dorsal muscles contracted in the span bend.)

Heaving Exercises. These involve chiefly the muscles of the back and front of the thorax, the shoulders, and the arms. The heaving

exercises as a whole bring great strain upon the muscles called into action; but they are so designed that at the point when the greatest strain is reached, i.e. when the final position is taken up, the thorax is brought into a posture ideal from a physiological point of view. It is chiefly in these exercises that the Swedish beam takes the place of the horizontal bar, now fortunately a thing of ill-fame.

The heaving exercise is represented in the introductory table by the 'arms bend' position.

As it is very important that this position should be taken up correctly, I will describe it in detail, using the 'arms bend' position as an illustration.

Starting in the 'standing' position, the arms are first fully rotated outwards and then flexed at the elbows, which are *drawn forward as far as possible,* whilst fully adducted, and the *hands are kept back* so that the fingers, flexed at the metacarpo-phalangeal joints, are brought to the point of the shoulder by slightly flexing the wrists.

This is a very difficult attitude for the novice to assume, and most difficult for strongly developed men who have not been properly exercised. The position, which is peculiarly beneficial, occurs very frequently in the arm exercises, because the 'yard', 'stretch', and 'reach' positions are all taken up in quick exercises by first doing arm bending.

The chief muscles are affected as follows (given in the order in which the movements are performed):

In rotating arms outwards.

Contracted.—Supinator brevis: Biceps: Infra spinatus: Teres minor.

Relaxed.—Latissimus dorsi: Pectoralis major: Subscapularis: Teres major.

In bending elbows.

Contracted.—Supinator longus: Biceps: Brachialis anticus: Coraco-brachialis.

Adducting arms, drawing the elbows forward and keeping the hands back so as to touch the point of the shoulder with the fingers—a difficult act of co-ordination.

Teres minor and *infra spinatus* are very strongly exercised in opposing the powerful internal rotators, which are themselves contracted just strongly enough to bring the elbows well into the sides.

Latissimus dorsi.
Pectoralis major. } Relaxed during the external rotation, then contracted as above, after the position of external rotation has been fixed and held by the above two muscles. The Trapezius, helped by the rhomboids and levator anguli scapulæ, is contracted in drawing the shoulder backward. The common fault seen in this exercise

is that the hands are held too far forward and the elbows too far back, owing to the failure of co-ordination between the external and internal rotators of the humerus. This is best obviated by taking up the position in the order given above. If the position is not held correctly it fails entirely in its effect.

Although there is not space to go into the muscular actions of the other group exercises, an exception has been made in the case of the 'arms bend' position because it is often not understood, and is of such great importance. Only those muscles that are typically concerned in the exercise have been mentioned, though of course the heaving exercises involve many others in addition.

As already mentioned, the effect of strong heaving exercises is to leave the muscles involved in a state of hypertonus, and the immediate nervous influence of these strong exercises is such that the finer control of muscular movement is lost for a time. It is important to restore this at once, and so it is at this stage of the table that the balance exercise should be introduced.

Balance Exercises. The influence of these is essentially a nervous one, and depends on the co-ordination of muscular control.

Progress is made by gradually reducing the base and increasing the height of the apparatus.

They may be divided into two groups, the first containing exercises in which the base is reduced only so far as definite form and precision can be given to the movements, the second containing those in which the base is so far reduced that in order to keep the balance, counter-balance movements are needed.

The first group is only for teaching 'form'. The second should always be used for 'fining down' movements after exercise.

In the gymnasium the following is a good order of progression :

1. A line drawn along the gymnasium floor.
2. Benches.
3. Beams.

4. 2 and 3 combined, the end of a bench being hooked on to a beam so that the class walk up the bench on to and then along the beam.

In addition, progression is made by altering the starting position and exercise. For example :

1. Yard standing.
2. Wing standing.
    (*a*) Marching sideways.
    (*b*) Marching forwards.
    (*c*) Marching backwards.

(*d*) Marching with knee raising.

(*e*) Marching with knee raising and forward stretching ('Goose' step).

Overbalance should be corrected by quick lateral movements of the pelvis, *not* by swaying the shoulders.

A good carriage should be maintained, and is helped by keeping the eyes forward and slightly up. The natural tendency, which is wrong, is for the class to look down at their feet.

Balance exercises use up very little power, but their effect on the nervous control is very great. At first the movements will be much too large, but they will be fined down with practice.

The centre of gravity is about the eleventh dorsal vertebra. When one knee is up-bent, the body should fall back from the other ankle, otherwise the hips must come forward with loss of correct position. The position of the head and shoulders is very important.

The head should be carried high and the shoulders slightly back. A good way to teach balance at first is to do knee-bending exercises in class and progress from there.

Dorsal Exercises. The tendency of these is to straighten the dorsal curve of the spine and raise the ribs, thus stretching the abdominal and anterior thoracic muscles, while the dorsal muscles are contracted. They are most important in kyphosis, and are of particular importance in those cases where misapplied exercise has led to over-shortening of the abdominal and anterior thoracic groups.

Great care should be taken that these exercises are performed so that the backward curve takes place in the dorsal and cervical, and not the lumbar portion of the spine, the last being a common fault; also that the hips are not brought forward, as in that case the efficiency of the exercise is destroyed.

The dorsal and abdominal exercises are placed together in the table as each stretches the muscles contracted in the other, and the dorsal should be placed before the abdominal because correct backward bending is not easily taught, and if the powerful abdominal and anterior thoracic muscles have recently been strongly contracted, their condition of over-tone makes the dorsal curve harder to attain correctly, and the faults illustrated above are more likely to arrive.

The position of the neck is very important, and careful watch should be kept, especially in the stretch position, that the head is not allowed to come forward.

Abdominal Exercises. An abundance of heavy abdominal exercises is wrong, and those of this group are apt to be overdone. It is of the greatest importance that the muscles forming the abdominal wall should be maintained always in good condition because their yielding, later in

life, leads to evils which are well known. In the introductory remarks to this article, it has been stated as an axiom that muscles which are developed out of proportion to their future requirements are certain to become ill-toned and flabby. This axiom should be particularly borne in mind when the abdominal exercise is given.

Leg-raising exercises are less likely to over-develop the abdominal muscles than those in which the trunk is raised with the legs fixed, e.g. 'fall sitting' from a bench, which should be given with careful consideration in the case of heavily built men, and the body not allowed to fall back so far that clonic contraction of the muscles is produced in raising the trunk. This last sign may be used as a guide to progression in the more advanced abdominal exercises, which should not be repeated more than two or three times at the most.

It is not meant to convey the impression that abdominal exercises are not of great importance, but here perhaps more than in any other group, the maintenance of good tone should be the object in view. It should be remembered that the abdominal muscles will again be exercised in the following group.

By raising the front of the pelvis the muscles of the abdominal wall, especially the rectus, reduce the lumbar curve.

Lateral Exercises. These are of great utility, contracting and stretching the abductors of the femur, the muscles of the abdominal wall, of the spine and thorax. In side bending they are of value in stretching the spinal and intercostal muscles of the opposite side. In this respect they are, of course, specially called for in cases of scoliosis, and of all apparatus available for lateral exercises I would specially recommend the window-ladder, because in climbing both up and down, as well as horizontally, if the exercises are properly set, the bend can be made always to the side desired, and is of especial mechanical advantage in cases of lateral curvature, because the lateral effect is much enhanced by the combination with strong heaving movements which window-ladder exercises entail.

If desired, when patients suffering from lateral curvature are being exercised on the window-ladder, the movement can be arrested at the stage when the hand hold is taken, and the patient made to do deep breathing in the desired position.

Jumping and Vaulting. In this group all the muscles of the body are brought into play. Many of the vaulting exercises on the horse call for great courage, coolness, and judgement, and are useful in developing these. 'Taking off' and 'landing' should be performed with as little effort and as much freedom of movement as possible. On no account should a spring-board be allowed, or a mat for landing. 'Taking off' and 'landing' should both be done upon the bare floor.

Breathing Exercises. Under this heading a quotation is made from the *Royal Naval Handbook of Physical Training* :

'When breathing has been disturbed to any great extent, short, hurried respiration continues for a certain period after the effort has ceased; then as the distress becomes less acute, one or two deep inhalations are taken which have the almost immediate effect of calming the distress and reducing the laboured breathing to more normal proportions.'

This fact is utilized in physical training with the addition of arm and trunk movements which have an expanding effect on the chest walls, thus allowing more air to enter the lungs.

The following points should be remembered :

1. That the exercises should not be employed at a time when the breathing is greatly accelerated ; a light leg exercise such as 'marching', 'marching on the toes', 'knee raising', &c., should be used until the breathing is more under control, then the exercise from this group should be performed.

2. That these movements should not be performed more than twice or at the outside three times in succession.

3. That an exercise from this group can be used anywhere in a table when breathing has been somewhat disturbed.

4. That whenever possible they should be performed in the open air.

5. That the movements should be performed quietly and evenly, and at no time should the breath be held.

Of all breathing exercises perhaps the best is 'arms circling with heel-raising'. As the heels are raised, the arms are brought forward and upward during inspiration, then backward, sideways, and downward during expiration, with heels sinking.

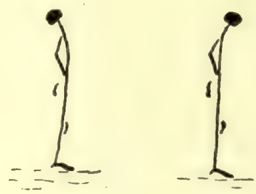
We have all experienced the peculiarly pleasant sensation of relief on having a good stretch after a long spell in a resting position. This is due partly to the stretching of the intercostal muscles and of the muscles that raise the chest wall. There is no other breathing exercise in which this relief is experienced so strongly as the one mentioned above, and even at the sacrifice of variety I never employ any other breathing exercises as a correction in a general table.

The particular efficacy of this exercise is that at the beginning of the movement, as the arms are rising upward and forward, the breath is inhaled and pectorales major and minor are contracted in raising the ribs. Just as they have contracted to their fullest extent, with the humerus and acromion process well forward, these two points of insertion of the pectorals are carried backward, and draw back with them the contracted pectoral muscles at the end of the inspiratory movement, drawing the ribs still further upward, while the backward, sideways, and downward movement synchronizing with expiration, first stretches the

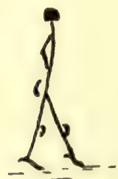
relaxing pectorals and then relaxes them as the hands are brought forward to the sides.

The object of raising the heels is to prevent the body from being bent backwards, the necessity for balance rendering this impossible.

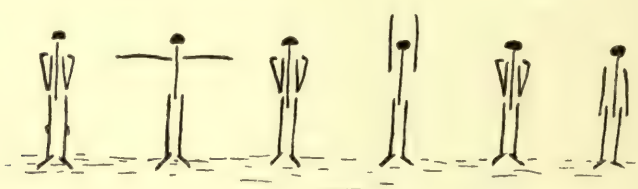
The following is an example of a full table of light exercises suitable for an introductory table :



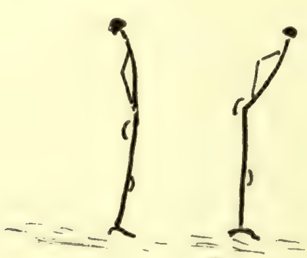
Head bending. *Head.*



Foot placing outwards with heel raising. *Light leg.*

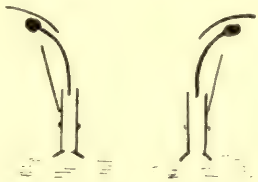


Arm stretching sideways and upwards. *Arm.*
(Arm bending takes place of heave.)



Trunk bending backwards and forwards. *Dorsal.*

Trunk bending downwards. *Abdominal.*



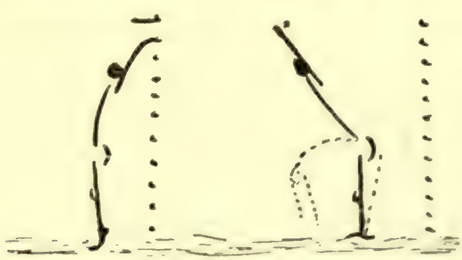
Trunk bending sideways. *Lateral.*

Heel raising and deep knee bending. *Strong leg.*

Arms circling and heel raising. *Breathing.*

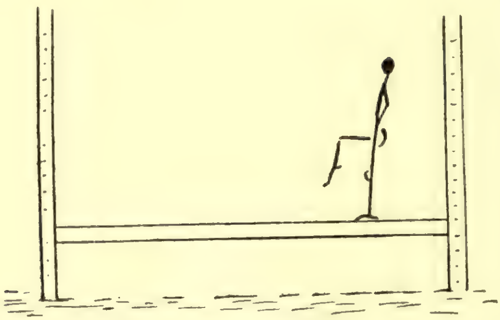
The above is a well-balanced table, exercising proportionally every muscle group of the body.

Following this is given the middle table, going again over the same ground and exercising each group more strongly than before, and the exercises are doubled in order to lengthen the table.



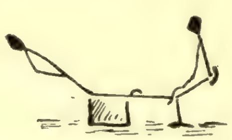
Span bend followed always by *trunk bending* forward and downward. (To stretch the dorsal muscles contracted in the span bend.)

Overgrip hanging, arm bending. *Heave.*

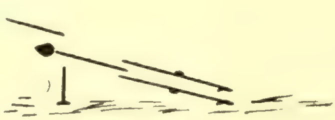


Balance walk (on beam) with knee upbending. *Balance.*

Wing forward lying, trunk bending backwards. *Dorsal.*

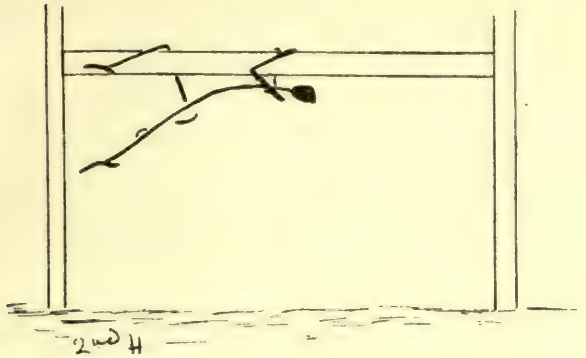


Wing sitting, trunk fall backwards. *Abdominal.*

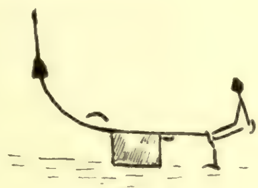


Half stretch, side falling. *Lateral.*

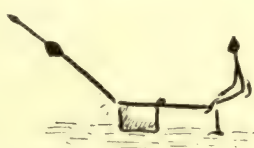
At this stage the class is given a deflective leg exercise and breathing exercise, and·is then put through marching movements into which can be introduced any special foot or leg exercises desired, and in cases where disabilities do not prevent it, vaulting and jumping exercises are given here.



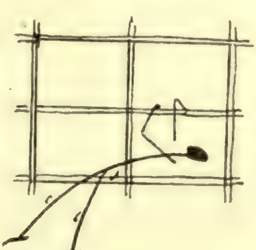
Horizontal hanging, climbing head first. *2nd Heave.*



Stretch forward lying, trunk bending backwards. *2nd Dorsal.*



Stretch sitting, trunk falling backwards. *2nd Abdominal.*



Window-ladders, horizontal climbing. *2nd Lateral.*

Finally the third table is given, consisting of exercises of the same nature as in the introductory table, so that every muscle group is exercised with quick light movements, after the heavy exercises of the middle table.

The above is a brief outline designed to illustrate the principles on which the Swedish exercises should be given. The introductory table

shown here gives a fair idea of the strength of exercises that would be given to hospital patients ordered Class ' A ' tables.

Those ordered Class ' B ' tables would be given the introduction table followed by the first half of the middle table, and the finishing table.

Those ordered Class ' C ' would be given all three tables.

The number of alternative exercises in each class is, of course, very great, and there is no space here for describing each one ; but I have in course of preparation a list that might with advantage be adopted in any orthopædic hospital.

REMEDIAL EXERCISES IN PARTICULAR, AND RE-EDUCATION

On reading pamphlets designed to teach remedial exercises for the qualifying examinations, it will be seen that in some of them a list of exercises is given, and statements made under each description as to the particular conditions each exercise is likely to correct.

This must make the subject very difficult both to understand and to remember, as remedial treatment cannot be laid down in this dogmatic manner. The first thing to do is to teach thoroughly the whole system of exercises and the physiological effect of each, and not their application to particular disabilities, until the whole subject is thoroughly grasped.

To understand the principles and practice of exercises properly, it is essential for the students themselves to go through a practical course in a gymnasium as well as to attend lectures.

Exercises must be *felt* to be understood, and no one can grasp their true effect and strength who has not performed them.

Having been given thoroughly to understand the exercises, disabilities may be shown and described to the students, and exercises suggested that are particularly suitable to each.

A few hints only are possible here.

When, for instance, an arm is to be treated in which there is limitation of movement in the elbow-joint, the surgeon should, when possible, make it quite clear to the operator what are the tissues limiting the movement, e. g. is the inability to extend the joint due to one or more of the following causes :

Wasting and shortening of muscles due to prolonged posture.
Shortening of muscle due to contracted scar tissue.
Adhesion in the joint itself.
Bony obstruction.
Peri-articular adhesions.

Often muscles contain contracted scars which have shortened them, and are at the same time wasted. Here it must always be remembered that side by side with the stretching of the fibrous elements the con-

tractile substance needs redevelopment in order to give the added length desired. When, for instance, the lower limb has been for months on a back splint, the quadriceps are frequently wasted to such an extent that their elasticity is gone and the knee in consequence cannot be bent. In such a case, forcibly to bend the knee is the greatest mistake because although the fibrous elements of the muscle have undergone little absorption, the reverse is the case with the contractile substance, so that this is badly injured and ruptured in any attempt to stretch it.

The first thing to do is, of course, to give graduated Faradic contraction to the muscles without bending the knee to any extent.

Only as the muscle is redeveloped should the joint be bent—as soon as a fair amount of movement is possible without straining the muscle, exercises may be given and after each application a light stretching applied. In fact, to speak in a popular manner, the muscle while being developed should be made frequently to feel the need of greater length.

I have seen a case in which the biceps brachialis had been wounded and shortened by scar formation, badly thrown back in the midst of recovery under exercise, by the forcible extension of the joint under gas. The fibrous tissue no doubt had been stretched satisfactorily, but the rarified contractile substance had been badly ruptured, so that the muscle had been ' strained ', and for weeks after, any attempt at extension was accompanied by pain, and this caused the patient to keep his arm constantly flexed, besides inhibiting voluntary extension during exercise.

Besides the recognized Swedish apparatus many exercisers are now on the market, some of them faulty.

There is one in particular which I must mention here, as it is so thoroughly useful. I allude to the sculling machine that I had installed and used at the Military Special Surgical Hospital at Tooting. So invaluable is it, that I regard it as indispensable in any remedial gymnasium.

A word of warning should here be given on the subject of ' pulley weight ' exercisers. Any apparatus which after resisting a movement pulls the limb back into its original position tends to spoil muscular co-ordination. It was for this reason that pulley weight and elastic exercisers were abandoned by all educated rowing coaches after a short trial.

The ' Sandow ' exerciser, for instance, is very bad. Muscles should be thoroughly relaxed frequently during exercise. A pulley weight or elastic machine tends to prevent this. For instance, if the arm is flexed against the resistance of such an apparatus, the weight, in pulling the arms back to the extended position, maintains the strain upon the flexor muscles, which are thus kept in a state of contraction during the extension movement, and are never completely at rest. The same objection applies to almost every exercise in which the pulley weight is used, and

reference to the remarks in the first part of this paper will show how bad a principle is here involved.

The fact is that, generally speaking, all apparatus used in exercise should be passive. No ' live ' apparatus is good.

To exercise muscle by hitching a man's arm or leg on to a pulley weight or piece of elastic is like playing some wretched fish—in whatever direction the movement is made, line is paid out or drawn in, and the steady relentless resistance kept up.

The re-education of patients recovering from motor-nerve injury is a very important subject. It should be begun as soon as there is definite evidence that continuity between nerve and muscle is well established. To start before this is a great mistake. Probably many functional disabilities are produced by frequently exhorting patients to contract muscles which have not yet recovered their nerve supply. To do this day after day when there is no possibility of the patient's responding to the exhortations of the operator, exhausts and discourages him and accustoms him to failure.

Not until a good Faradic response is established should these measures be adopted. Then every effort should be made to restore vigour of movement. Quick exercise should be the order of the day. In a recovering Median, for instance, finger bending should be taught with little quick jerks. These will bring about a greater strength of volition than slow movements, and it must be remembered that just as it requires a stronger Faradic stimulus to make the muscles contract in the early stages of nerve recovery, so must a greater effort of will be made to bring about the same result.

Very pretty and interesting little tables of exercises can be made out for recovering nerve lesions. In dealing with the hand and arms, for instance, the musculo-spiral, ulnar, and median nerves should have each its special table.

Space, unfortunately, does not allow more than the foregoing sketch of a large subject, but it is hoped that the lines laid down above will be adopted, and some scientific method brought into remedial gymnastics which should be based on a knowledge of physical training applied as an educational subject.

HYDROTHERAPY

BY

R. FORTESCUE FOX, M.D., F.R.Met.S.

Consulting Physician in Hydrology at the Special Military Surgical Hospital, Shepherd's Bush

HYDROTHERAPY

HYDROTHERAPY is the application of the energy of *heat* and *cold* and *movement*, through the medium of water and vapour, as well as by direct radiation—both to the whole body and to parts of the body.

The rôle of hydrotherapy in surgical practice is to promote the restoration of function by assisting the healing of wounds ; by restoring defective circulation of blood and lymph, by removing œdema and inflammatory products ; by increasing the mobility of limbs and the nutrition of wasted muscles ; by relieving pain, and accelerating convalescence by stimulating the nerve centres.

The action of hydrotherapy is either *tonic* or *sedative*, whether applied to the whole body or to injured parts. The systematic and routine use of tonic hydrotherapy in military hospitals is a powerful means of improving the general health and *morale* of the patients and of preventing illness and debility. Sedative hydrotherapy is directed to the relief of pain and of neuro-vascular disorders marked by rapid action of the heart and undue excitability of the nerve centres.

Hydrotherapy was first applied systematically to military cases at the Physical Clinic for Wounded Officers (now the Red Cross Clinic) in London. In this pioneer installation it was recommended both for medical and surgical cases, sometimes as an isolated method of treatment, but more particularly as an essential part of a *combined physical treatment* for disabled men, which includes remedial baths, manipulation, exercises, and electrical applications.

Local baths for injured limbs, and general hydrotherapy, were afterwards set up at certain command dépôts and military hospitals, and have been extensively used for convalescent cases, both medical and surgical. Lastly, a more complete and specialized type of hydrotherapy for military cases has been installed at the Military Orthopædic Hospitals.

The department at Shepherd's Bush, which may be taken as a type, was opened on July 24, 1917, and was constructed on a sufficient scale to admit of the treatment of a large number of out-patients. It was placed under the direction of a medical officer who had specialized in experimental hydrology. The medical officer's staff consisted of twenty-one assistants, including a corporal, three consulting-room clerks, two clerks for recording temperatures and pulses and for booking attendances, three manipulators, and two attendants for each of the following : the

douche-room, the contrast baths, and radiant heat, and four cleaners. All the assistants employed in the department are patients in the hospital. 35,181 treatments were given during the first year, comprising

Whirlpool baths	23,283
Hot and cold douches	5,831
Contrast baths	1,989
Radiant heat baths	1,670
Aeration baths	1,500
Massage-douches	395
Sitz baths	207
Showers	168
Pool baths	134
Paraffin baths	5
	35,181

The nature of the cases treated are as under :

Deformities.	Myalgia.
Fractures.	Neuritis.
Dislocations.	Nerve injuries.
Wounds of joints.	Trench foot.
Contusions.	Neurasthenia.
Arthritis.	

Results of Treatment. It is difficult to form an exact estimate of the results of any method of treatment when other kinds of treatment are being used at the same time, as is most generally the case with hydrotherapy. A good indication may, however, be obtained from the patients themselves, who are often men of much intelligence. Many of them say that they have begun to improve since the douches or whirlpool baths were commenced. The testimony of the attendants and manipulators is also of value. An intelligent manipulator soon discovers if the fingers or knee-joints are becoming more flexible in the baths or if the colour and circulation in the limb or the muscular power is improving. Those who are daily employed in the actual treatment have generally a good opinion of the value of hydrotherapy.

Measurements and Records. Lastly, there is the crucial test by accurate measurement of the mobility of joints, or of the power of muscles. Separate measuring instruments for the various joints, or one combined arthrodynamometer, are an essential part of the equipment of a department of hydrotherapy. At Shepherd's Bush, as at the Red Cross Clinic, periodical measurements of movement are recorded every week or fortnight on special case record cards, together with notes as to the progress of the case and of any change of treatment. The periodical measurement

of the power of wasted or paralysed muscles is not less important. It is easy to record the strength of the hand-grip by a spring dynamometer. The power of other movements and the onset of fatigue can be shown by Sonntag's arthrodynamometer. A variety of accurate measuring instruments, both for movement and muscular power, is required for recording the condition of the wounded under treatment of hydrotherapy.

Duration of Treatment. Remedial baths are usually given daily for a period of weeks, which may in suitable cases be prolonged for several months. A course of hot (thermal) baths should not be continued for more than three or at most four weeks, otherwise 'thermal debility' may be induced. Baths below blood heat (subthermal) may be continued daily for a long time, without any risk of debility. Brief tonic douches may be given daily for an indefinite period during convalescence, with excellent effect. Local baths (whirlpool, vapour, hot air, or radiation) may be applied daily to an injured or paralysed limb. After a month's treatment the effect of the bath on the circulation, mobility, and muscular power should be accurately determined, and if the result is good the treatment may be continued for a second and third month. After three months it is well to intermit treatment. In chronic cases a second course of treatment may be given, when three or four months have elapsed.

Hydrotherapy combined with other modes of Physical Treatment. Hydrotherapy is of great value when used in connexion with manipulations and physical and gymnastic exercises and with electrical treatment. If an injured limb or scar is sensitive to touch, or if movements are painful and are resisted by the muscles, hydrotherapy is the best *preparation for massage*. After the bath the tissues can often be manipulated and the joints moved without pain. The hyperthermal whirlpool bath softens the tissues, relaxes muscular spasm, and acts as a local anæsthetic. The anæsthetic action of the whirlpool bath is one of its most valuable features. The massage and hydrotherapeutic departments should therefore be closely associated, so that the injured limb, on the termination of the whirlpool bath, can immediately be submitted to massage. *Subaqueous massage* is given in certain kinds of baths, such as the massage-douche and the manipulation bath, and is especially applicable to weak and sensitive subjects, and to painful or hypersensitive limbs. Local baths are of assistance before electrical treatment, by increasing the conductivity of the superficial tissues.

Tonic baths (brief douches and salt-water frictions) are used as a *sequel to exercise*. The harder and more prolonged the physical exercises or training, in the gymnasium or open air, the more appropriate is a tonic bath, like the school bath after games.

Hydro-massage. This is the name given to the mechanical stimulation of the limb immersed in a current of water—as in the turbine whirlpool

bath. The movement of the water may be slow and gentle or more powerful and rapid, and may be increased at will or its direction reversed. The impact and friction of the water produce an effect similar to that of skilled manipulation, but the action is more continuous, and can be prolonged at will. Many limbs, and some with open wounds that are not yet in a condition for manual treatment, can be treated with advantage by hydro-massage.

The Co-ordination of different forms of Physical Treatment. Hydrotherapy, manipulation, passive movement, active exercise, and electrical applications may be given separately and singly, but produce their *optimum* effects when skilfully combined. All these physical remedies have the same general purpose, and may be made to supplement and assist one another. In the treatment of injured limbs the following sequences are commonly observed, in which two or three operations are combined, beginning with hydrotherapy:

Water (heat) (1) accompanied by hydro-massage.
(2) ,, ,, manipulation.
(3) followed by manipulation or massage.
(4) ,, ,, massage and mechanical treatment.
(5) ,, ,, exercises or mechanical treatment.
(6) ,, ,, electricity and mechanical treatment.

METHODS OF HYDROTHERAPY

Whole Body Baths.

(1) **The Douche.** This is a jet, spray, or shower of water, usually at high pressure (30 to 50 ft. head, or 10–15 lb. per square in.), and at any temperature from cold to 110° or 115°. The hot and cold supplies are blended to the prescribed temperature in a mixer. It is of great importance that the hot supply should have a nearly even temperature, and approximately the same pressure as the cold, otherwise the stronger current may master the weaker one, and dangerous inequalities of heat appear in the douche. The impact of a high-pressure jet, hot or cold, is a very powerful form of stimulation (the equivalent of a hard blow), and may cause considerable bruising. Delicate persons should not be subjected to it. Douches at high pressure should not be directed to the front of the chest or abdomen, but are usually well borne on the spine and lower limbs. Instead of the powerful percussion of a single strong jet, the gentler stimulus of many finer streams may be used, as in the *rose-douche,* or by a circular arrangement of very fine apertures, in the *needle-bath,* or by water falling vertically in the familiar *shower-bath.*

In all these and every other form of the douche the movement or energy of the water plays an essential part. Observation has shown the

prime importance of *movement* as a factor in the action of douches, flowing baths, and whirlpools. The influence of sedative or stimulant movements in these baths is added to corresponding impressions caused by varying degrees of heat or cold The effect so produced upon the body is quite different from the sole effect of temperature. The douche, of whatever kind, is given at first warm, about 90°, rises to a little over 100° or at most 110°, and finishes cold or nearly cold after one or two minutes.

The cold douche, spray, or shower should produce a definite physiological 'reaction'. In the healthy subject it stimulates the action of the heart, deepens and quickens the breathing, and increases tissue oxidation and the formation of bodily heat. If 'reaction', as shown by increased warmth and vigour, does not occur, the cold douche, like the cold plunge bath, is inapplicable and may be injurious. The degree of reaction in convalescent soldiers must always be observed. The daily use of the douche, especially if heat is used before cold, improves and 'educates' defective reaction. Brief cold douches are used as a general tonic in the convalescence both of surgical and medical cases, to stimulate languid circulation and defective nervous responses, and in many cases of neuralgia and functional paralysis.

Hot and cold or *contrast douches* are applied by two jets, differing 40° to 50° in temperature. They are applied simultaneously to adjoining areas, especially over the spine and shoulders, and locally to stiff and swollen joints and to unhealed and indolent wounds. Any pressure can be used, from the gentlest upwards to 10 or 15 lb. to the inch. The contrast douche is a very powerful stimulant, indeed the most stimulating of remedial baths. It excites a kind of circulatory gymnastic, and is better borne than the cold douche. It is valuable in many conditions of depressed nervous and circulatory tone, both of the whole body and of injured parts. Its use requires a skilful and experienced operator.

Massage-douches at low pressure. The patient is seated on a stool or, better, reclines in a wooden trough. The water, carefully mixed to a subthermal temperature, pours over the body in a large unimpeded stream, *without pressure*, from an open mixing-chamber. Massage and manipulation are given under the stream of water to the whole body or to injured parts. The soothing effect of the water often enables painful limbs to be manipulated with comfort. It should be remarked that this form of douche may be given to persons in very low conditions of health, if they can be carried from their beds to the douche-room. The heart's action usually improves in strength and diminishes in frequency during the bath, if properly administered.

(2) **Thermal Baths (brief).** Baths at or over blood-heat relax muscular spasm, quicken the pulse, and improve the action of the skin. Their *duration must be strictly limited*, for if continued beyond an average of

fifteen minutes they may cause considerable debility and temporary dilatation of the heart. The addition of salt makes them more tonic. Such baths, either of natural thermal water, as at Bath, or artificially prepared, are used for rheumatic persons and those having a subnormal temperature, to increase circulation, to promote the nutrition of paralysed muscles, and facilitate the movements of joints.

(3) **Subthermal Baths (prolonged). The Sedative Pool Bath.** Baths at or about the average temperature of the skin (93°) *can be continued for an indefinite period.* They equalize, and on the whole stimulate, the circulation, and are powerfully sedative to the nerve centres. The water should be kept at the same point of temperature, and should never be allowed to become stagnant, but be constantly renewed by a gentle flow through the bath.

The Hammock Bath is used for unhealed wounds, especially in septicæmia, after counter-incisions, in order to cleanse the wounds and promote discharge. This especially applies to wounds of or near the trunk, to which local baths cannot be applied. This bath is to be recommended not only for its local effect upon infected tissues, but also for its sedative and gently stimulating effect on nervous and febrile subjects. Patients may remain for several hours or days in these baths. Sea-water has been used with good results in many cases. The proportion of salt ought to be about 1 per cent., to render the bath isotonic with the body fluids.

The hammocks used for acute surgical cases must, of course, be simple and readily sterilizable.

The Sedative Pool Bath has been devised for soldiers taking baths in numbers. The smaller pools accommodate four to five men comfortably seated, the larger pools ten or twelve. The temperature is maintained by an automatic regulator at 93° to 95° in winter, and 90° to 92° in summer. The water is constantly flowing. Some pools are fitted with inlets for compressed air, which add to the gentle movement of the water. This bath is used for painful scars, especially of the trunk, for neuritis and muscular spasm, as well as for disordered action of the heart, and nervous and mental excitement and shell shock—conditions of general disturbance to which surgical cases are sometimes liable. The sedative pool bath is also of much assistance in insomnia. The pool room must be kept very quiet and undisturbed, and the light subdued. An attendant is always present, but conversation is not encouraged. Upon leaving the pool, the patient returns to his bed, or lies down in an adjoining resting room.

(4) **Vapour Baths.** These are given at any temperature from 80° or 90° to 130° F. The Russian bath is a bath of saturated vapour, at or about the limit of toleration of the body for moist heat (125° to 130°). It acts as a most powerful stimulant to the skin and peripheral circula-

tion, and is therefore to be recommended, especially in winter, to people who 'feel the cold' and seldom perspire. Vapour baths at lower temperatures are soothing and sedative in neuritis and painful scars, and the moist heat of the bath removes epidermic accumulations and makes the skin soft and supple.

(5) **Aeration Baths.** These are immersion baths, in which the water is broken into foam or bubbles by compressed air. Like the natural surf or wave bath, the aeration bath is far more stimulating than still water, and is used as a nervine and circulatory tonic for many wounded and debilitated men who are not strong enough to bear the douche.

(6) **Radiation Baths.** Radiant heat and light baths are given by exposing the body to electric lamps, arranged either in a vertical cabinet, in which the patient is seated, or on either side of a couch upon which he lies recumbent. The cabinet may contain 30 to 50 16-c.p. lamps, the recumbent bath half that number. The couch bath is preferable, as the position of the body is more restful. Arc lamps, with carbon or tungsten terminals, are sometimes recommended instead of ordinary incandescent lamps. Their radiation, like that of the sun, is rich in ultra-violet rays. The action of the various rays upon the body has still to be determined, but it is known that radiation baths powerfully stimulate the circulation —at first the superficial vessels and then the deeper ones—relieve pain and induce perspiration. Individuals differ widely in their reaction to these baths. In some the superficial capillaries expand and the skin acts freely when the temperature within the cabinet rises to 100°. Others require a temperature of 140° or 150° for twenty minutes or longer to produce the same effect. Whilst the patient is in the radiation bath, cold compresses should be applied to the head, and when he leaves it a cold shower or sponge bath should be given. These baths are of much value to chilly subjects with defective peripheral circulation and tendency to internal congestion, also to increase elimination in many chronic toxæmias (rheumatism, septicæmia, &c.) and in convalescence.

(7) **Manipulation Baths.** As has been already stated, manipulation is often most effective when given *within the bath*. Stiff and painful knees, hips, or shoulders can be sometimes manipulated without pain in a deep thermal bath, and the same applies to limbs contracted from old paralysis. This practice has been followed for many years at some of the natural thermal baths. It can be best done when the patient is seated in a deep bath with the water covering his shoulders. The water may be still or aerated. A movable cross-bar should be fitted in the centre of the bath, to serve as a support to the thigh in cases of flexion of the knee. In many cases of stiffness of the hip, the best results are obtained by manipulation and movement under water. Active movements may be readily performed under water, which are otherwise quite impossible. A limb

immersed in water is moved with comparatively little muscular effort, since its apparent weight or resistance to movement is reduced. The apparent reduction of weight of a leg, for example, immersed in water, is very considerable, equalling the weight of the water displaced by the limb. A swimming bath or pool of warm water, in which manipulation can be given by an attendant, is consequently of much value to men with stiffened and painful limbs, who may with advantage spend a portion of each day in the water.

The employment of massage in low-pressure douches has been already described.

Local Baths.

Local or limb baths are methods of applying the energy of heat and cold and movements in various media. These may be *liquid*, such as water, oil, or melted paraffin; or *gaseous*, such as vapour or hot air; or *solid*, such as heated sand or salt. The greater part of the upper or lower limb can be immersed in local baths of this kind, but not the shoulder, hip, or trunk.

(1) **Whirlpool Baths.** These are extensively used for the limbs after wounds have healed, and special forms of whirlpool have been devised for the hand and forearm, for the feet, and for the thigh and leg. In the turbine whirlpool bath a powerful rotatory movement is given to the water by the revolution of a fan, protected by a grating at the bottom of the bath. In the jet whirlpool a series of jets of water at very high pressure enter obliquely the side of the bath, and communicate their movement to the whole mass. This method has been elaborated at the Red Cross Hospital at Netley, and is known as the 'Netley bath'. In a third form of whirlpool, an irregular movement is given to the water by the entrance of compressed air. The turbine and jet baths are therefore real 'whirlpools', while the air bath, strictly speaking, is not.

The whirlpool bath for arm, foot, or leg is usually given at 110° to 115° F. for fifteen or twenty minutes. The part may be manipulated in the bath, or immediately afterwards. Where a considerable extent of body surface is exposed to such a bath, as for example the lower limb, the body temperature commonly rises 1° or 2°, and there is a profuse perspiration. After such baths a cooling spray or shower-bath is generally given. The limb, arm, or leg is moreover often greatly heated by the bath, and a cool or cold spray upon it is agreeable and beneficial in most cases.

The whirlpool bath is given in cases of recent fracture both as a local anæsthetic and for hydro-massage. Pain, swelling, and stiffness, induced by pressure and confinement in splints, are relieved by it, and the languid circulation in veins and lymphatics restored. In recent fracture of the

forearm, the moving water is a sufficient support to the limb (*vide infra,* Recent Fractures). More chronic cases of defective circulation, œdema and stiffness of the joints and muscles, induced by splinting or long immobility are also often amenable to the whirlpool bath. The stiffness so commonly met with in a joint (e. g. knee or elbow) in proximity to fractures may be prevented or removed by the use of such baths. It is believed that they are sometimes useful in stimulating the formation of new bone. Other indications are painful scars, neuritis, trench feet, chilblains, and cases in which the circulation has been diminished by closure of one or more large arteries as in operation for hæmorrhage or aneurism, or from obliterative arteritis. In these cases a course of hyperthermal whirlpool baths (115° F.) increases collateral circulation. Such baths must be used with caution where there is anæsthesia from nerve injury, and also where the superficial veins are enlarged or varicose, and they are also contra-indicated if the limb is inflamed or even congested, as in recent synovitis.

(2) *Local Subaqueous Douches and 'Eau courante' Baths.*—Unhealed or septic wounds and cases in which it is desired to facilitate the separation of dead bone can be treated with advantage by the warm (100°) subaqueous jet or douche, given in an earthenware vessel. Flowing water in an arm or leg bath of this character can also be used in such cases (*Eau courante*). Unhealthy ulcers and sinuses are treated in the same way. These methods are more cleanly and in every way preferable to limb baths of standing water. The temperature of the subaqueous douche or flowing bath is usually 100°, and the duration from twenty minutes to one hour or longer—twice or three times daily. Earthenware vessels for septic wounds of the foot, leg, and arm, with douche attachments, can be readily fitted in any hydrotherapeutic department.

(3) **Contrast Baths.** These are two adjoining baths or troughs of flowing water, with a difference of 40° to 60° of temperature. For the arm a hot and cold whirlpool bath are arranged side by side ; for the feet, parallel troughs, where one or more men, seated on stools between the troughs, can be simultaneously treated. The limb (foot or arm) is placed for thirty seconds in the heat and for fifteen seconds in the cold, again in the heat and again in the cold, and so on for twenty or twenty-five minutes once or twice daily. Contrast baths are used for trench feet and neuritis, and for sluggish circulation of the extremities after wounds or injuries.

(4) **Local Radiation Baths.** Any convenient source of radiant heat, such as a coal fire or ordinary electric reading lamp, may be utilized for local applications to injured limbs and for neuritis. A more powerful incandescent lamp, of 50 or 60 c.p., enclosed in a metal reflector and mounted upon a wooden handle, forms a very useful 'head lamp' for

treating parts like the shoulder, hip, or sciatic region, to which the whirlpool and other local baths cannot be applied. The lamp should not be fixed in one position, but kept moving about at a distance of six or eight inches from the affected part, for some five or ten minutes if the heat is well borne, care being taken not to overheat areas of anæsthesia. Such applications of radiant heat to the shoulder and hip joints are a very proper preparation for movement and manipulation, if pain and muscular spasm are present. They are also useful in relieving pain in brachial and cervical and lumbar neuritis, and in sciatica. In many such cases radiant heat is all that is required, and manipulation and movement more often than not injurious. The arc lamp, fitted with a parabolic reflector, can be used in the same way, if placed at a distance of five feet or more from the body. It may be successful in relieving pain when the incandescent lamp is of no effect.

What are called local radiant light and heat baths are given by enclosing the limb in a small chamber or appliance fitted with several incandescent lamps and metal reflectors, and provided with a thermometer. Special lamps for generating heat are usually employed for these appliances, and the air enclosed in the chamber becomes readily heated to 180° or 200°. This powerful radiation, direct and reflected, is more penetrating than that of ordinary lamps, and is therefore used where an effect upon the deep tissues is desired, as in cases of chronic fibrositis and arthritis, and sometimes old cicatrices and adhesions. The limb can be treated for fifteen to thirty minutes at a temperature of 180°, but care is required to avoid over-heating, and especially in anæsthetic areas.

Radiant heat powerfully promotes the local circulation, oxidation, and tissue change, and may therefore be used with advantage for indolent and sluggish wounds and ulcers, if not inflamed.

(5) **Local Hot-air and Vapour Baths.** Contracted and wasted limbs are sometimes treated by 'dark heat'. In the 'thermal air chamber' and other forms of local hot-air bath, the temperature of the included air may be raised to 250° F. or more without inconvenience, provided the moisture caused by evaporation is allowed to escape. The heat may be derived from spirit-lamps, as in the earlier baths of this kind, or from electrical resistance. The heat is communicated to the limb partly by radiation and partly from the super-heated air.

The limb subjected to this very powerful thermal stimulation becomes extremely congested, and, as is the case with the whirlpool bath, the general temperature may rise 2° or 3°. Such baths have been proved of real value in facilitating the movement of stiff and contracted joints, and in removing pain and swelling, especially in chronic arthritis. *Local vapour baths*, in which a moderate degree of heat is combined with moisture,

are much more soothing than hot-air baths, and have a useful place in the treatment of ulcers and painful scars, complicated with neuritis. The *hot-air douche* is a convenient method of applying a current of hot air to any part of the body, especially the trunk. It is indicated in many painful local disorders, and for slowly healing and painful wounds.

(6) **Local Paraffin Baths.** Hard paraffin in a melted condition has been found to be a convenient vehicle of heat. Owing to the relatively low conductivity of paraffin, and the fact that it becomes quickly congealed upon the skin, the bath can be taken with comfort at a temperature of 138° to 140°. The hand immersed in such a bath is almost immediately covered with a thick glove of semi-solid paraffin wax. Under this covering the sweat is retained and softens and macerates the epidermis, whilst the heat opens up the peripheral circulation and increases the glandular activity. Such applications may be used for softening indurated scars and increasing the vascular supply and cutaneous action where these are defective.

The following are some of the conditions met with in surgical practice that are amenable to hydrotherapeutic treatment:

Cases suitable for Hydrotherapy.

(1) **Convalescence.** Most convalescents are benefited by general hydrotherapeutic measures. Wounded men with a languid circulation and slow pulse may be given the daily tonic douche—cooling from 100° to 50° in two or three minutes. On the other hand, those who sleep badly, and men with rapid pulse, derive more benefit from the sedative pool bath or the friction brine bath. As a result of either of the last-named baths, after a few days the pulse often becomes much quieter, and the sleep tranquil and profound.

(2) **Unhealed Wounds.** In wounds where the skin has been extensively destroyed, cicatrization is promoted by *isotonic saline flowing baths* at an indifferent temperature (93°). The bath may be continued for an hour or more twice daily. In septicæmia the removal of septic discharges, the reduction of temperature, and the general condition are all favoured by long-continued *hammock baths*. These baths also should be flowing, and be kept constantly at the same point of temperature, 92° to 95°, according to season. In serious cases, the patient may remain many hours or days in the bath. Where a wound re-opens to discharge a sequestrum, or fails to close from defective circulation or power of repair, the *subaqueous douche*, given at 100°, accelerates healing by promoting discharge and stimulating the circulation. Chronic sinuses, with or without osteitis, are also stimulated by the subaqueous douche and by salt or *brine baths*.

(3) **Cases complicated by Nervous Shock and Strain.** Here again sedative hydrotherapy powerfully contributes to the general well-being and to the recovery from wounds and injuries. The two most useful procedures are the *sedative pool bath* and the *low-pressure douche,* with general sedative and subaqueous massage. After treatment the patient should be quickly returned to his bed or couch in a quiet resting room and encouraged to sleep. An attendant should note the frequency of the pulse, temperature, and respirations before and after treatment. The fall of the pulse rate, the rise of a subnormal temperature to nearly normal, with a sensation of well-being, are favourable signs, which indicate continuance of the treatment.

(4) **Recent Fractures.** Much may be done by judicious hydrotherapy to prevent the stiffness and wasting that often result from fracture of a limb. After the first week a fractured forearm may be cautiously submitted to hydro-massage in a whirlpool bath at 100°. The same treatment may be given from the beginning to Colles's and Pott's fractures and fractures of the digits. By this means effusion in the soft parts is minimized and the circulation maintained. This is of much importance where the fracture is in the vicinity of the elbow, knee, or wrist joints, in which cases a daily bath treatment of this kind may prevent stiffness of the joint. In fractures of the tibia or fibula, it is generally preferable to support the limb on a canvas sling, and to apply the low-pressure douche at 100°, with or without gentle subaqueous massage. The relief of pain, tension, and swelling is sometimes remarkable.

(5) **Stiffness and Swelling the Result of Prolonged Immobilization. Sprains and Strains of Joints.** All these conditions, failing any special contra-indication, should be submitted to hydrotherapy and manipulation. The manipulation may be given under water or immediately after the bath. It may be confidently stated that if injured limbs were treated by hydrotherapy at an early stage, as detailed in the previous section, much less ankylosis and wasting would be encountered after splinting, provided that the immobilizing apparatus can be removed safely for a short period for a daily bath, carried out as above described without any disturbance of the position of the limb. When splints are finally discarded, more active baths—whirlpools, douches, and manipulation baths—should be brought into use, and a daily note made of their effects. Stiffness, the result of fractures and immobilization, can usually be removed without difficulty by the manipulation bath in recent cases—the difficulties of treatment increasing with the duration of the case. It is a waste of time to submit ankylosis to hydrotherapy. But there are many cases in which the movement, say of the knee, is limited by deep cicatricial tissue in the muscles, or by a few adhesions in the joints, in which it is possible by heat, moisture, and movement gradually to soften

and stretch the newly formed bands which impede the movement. If in such a case careful measurements show that increased movement has occurred within the first week, this may be considered a good sign, and it is well to persevere. Commonly enough, however, after an additional movement of say 15° or 20° has been gained, the improvement comes to a sudden stop. In these cases subsequent manipulation under an anæsthetic may complete the cure, and this is often easily effected *after a course of hydrotherapy*. On the other hand, it is frequently found by the surgeon that no further movement can be gained under an anæsthetic when the full effect of hydrotherapy has been obtained. It may be definitely stated that movements under an anæsthetic ought to follow and not precede the use of whirlpool baths. The congestion and effusion produced by forcible movement or wrenching are very often increased by hot whirlpools and by manipulation. After surgical intervention a week at least should therefore elapse before baths are resumed. In cases of long standing, where there is no fluid in the joint or inflammatory reaction, it is a good practice to combine hydrotherapy (whirlpool baths) with special flexion and extension exercises in the gymnasium. When the limb is flooded with blood and the cicatrices softened by heat, daily increases of movement are often obtained in this way.

Recent sprains and strains of the joints, and other injuries of the soft parts, may be treated with local cold baths of flowing water. At a later stage, when the limb possibly has become stiff and swollen and shows a subnormal temperature, the appropriate treatment is by means of hot whirlpool baths and contrast douches, followed by manipulation.

(6) **Painful Scars.** Pain due to extensive scarring of the trunk is often relieved by a prolonged sedative pool bath. For many painful scars of the limbs, the hot whirlpool is equally useful. For causalgia cold subaqueous douches may be employed, and in neuritis from involvement of nerves one may use the local vapour, or melted paraffin, or the arc light bath. It may be well to employ two of these methods in succession, and to vary and alternate them until the treatment best adapted to the individual case is determined.

(7) **Cases after Suture of Divided Nerves.** During the prolonged period which intervenes between the suturing of a nerve and the recovery of muscular power, much can be done by hydrotherapy, combined with electrical treatment, to maintain the nutrition of the affected muscles. If the circulation is defective, hot whirlpool baths are indicated. These increase arterial supply, favour the removal of waste, and augment the electric conductivity of the tissues. Aeration baths, followed by brief hot and cold douches, applied to the spine as well as to the injured limb, make a good routine practice in nerve lesions. The hot and cold or contrast douche is a mechanical as well as a thermic stimulant to the muscles.

(8) **Trench Feet and Neuritis.** Where pain is a marked feature, local vapour baths as a preliminary treatment are indicated. Thereafter radiant heat, followed by alternating or contrast baths, should be used. It is a good plan to follow an ascending scale of thermal and mechanical stimulation, beginning with gently flowing water for a few days, and going on to full-pressure hot and cold douches, applied not only to the feet but to the spine as well.

(9) **Malingering.** No treatment is more decisive in the diagnosis and cure of malingering than the douche. When the attention is fully occupied by this powerful stimulant, feigned symptoms can with difficulty be sustained. The douche, skilfully given, is at the same time a powerful aid to psychical treatment.

Action of Remedial Baths.

The objects for which remedial baths (hydrotherapy) are employed in surgical practice may be stated as follows:

(1) To cleanse deep wounds and to promote the discharge of septic matter and sequestra.

(2) To favour the healing of indolent wounds, ulcers, and sinuses.

(3) To increase the blood and lymph circulation, open up collateral channels and remove effusions and œdema.

(4) To increase the mobility of joints and muscles by facilitating the stretching of fibrous tissue.

(5) To relieve pain.

(6) To allay muscular spasm.

(7) To promote the absorption of inflammatory deposits.

And in general:

(8) For their *stimulant* effect in convalescents with slow and poor circulation and atonic debility.

(9) For their *sedative* effect in nervous shock and strain, rapid circulation and irritable debility.

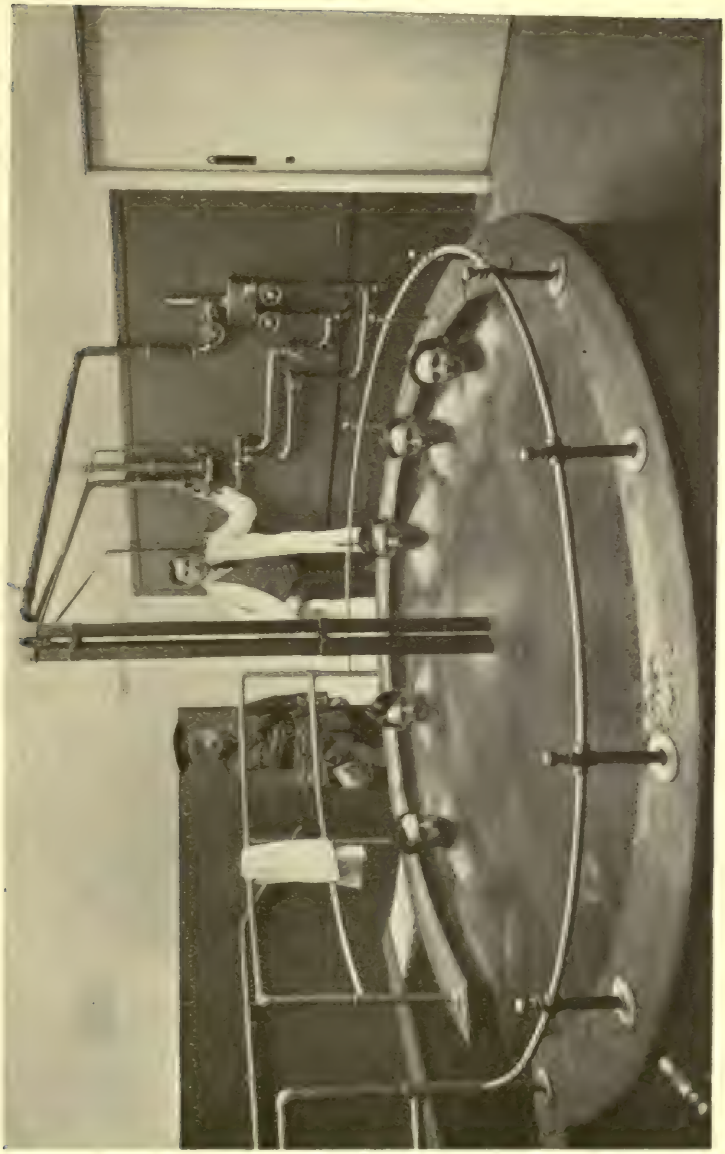


FIG. 234.—The Sedative Pool Bath at the Bellahouston War Hospital.

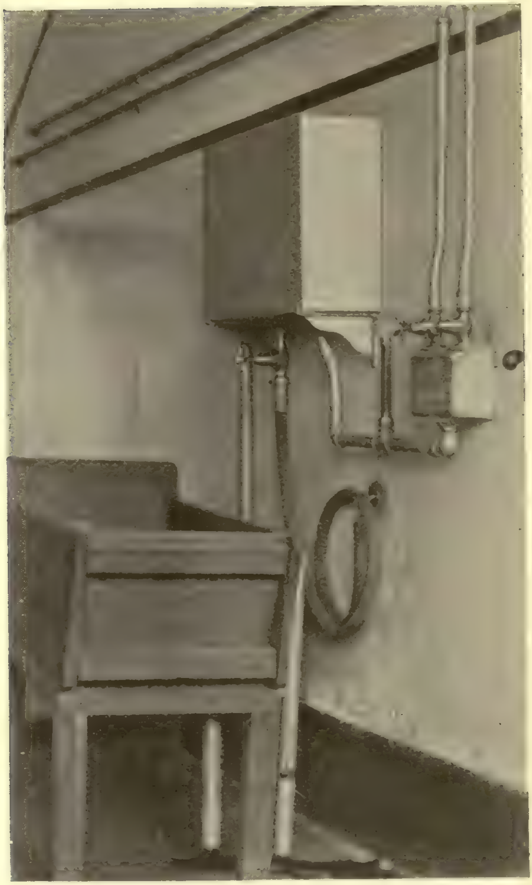


FIG. 235.—The Low Pressure Manipulation Douche (Shepherd's Bush Military Hospital).

FIG. 236.—Turbine Whirlpool Bath for the Feet (Red Cross Clinic).

FIG. 237.—Local Vapour Bath

ORTHOPÆDIC X-RAY WORK

BY

Major C. THURSTAN HOLLAND, R.A.M.C. (T.F.)

Western Command Expert, Member of the War Office Standing Committee on Radiology

ORTHOPÆDIC X-RAY WORK

PART I

To a large extent the X-ray work of a military orthopædic hospital is comparatively simple, and in the main resolves itself into dealing with two classes of conditions. The first, and larger, of these is the X-ray demonstration of various types of injury to bone ; the second is the detection of the presence of, and, if necessary, the exact localization of, foreign bodies. Additionally there will occur a certain number of cases such as are met with in civilian practice, and which cannot be classified in either of these two divisions ; these will include cases of tuberculous, syphilitic, and malignant disease of bone, deformities, congenital and acquired, and so on ; but these do not add materially to the nature of the X-ray work required from the points of view of either the difficulties or of the equipment.

It follows from this that a large and elaborately equipped department, corresponding to those found in big general civilian hospitals, is not necessary, and the work can be carried on efficiently in smaller rooms and with less apparatus.

The department should be preferably adjacent to the operating theatre, or at any rate in very close proximity ; easy of access from the wards ; and near to the lift leading to the different floors.

Three rooms are necessary, and these may be considered shortly.

1. **A Waiting Room** for the accommodation of patients either walking, in wheeled chairs, in the ward beds, on trolleys, or on stretchers. A point is that the door should be a sliding one and the opening of ample dimensions.

2. **The X-ray Operating Room** should open from the waiting room through a large sliding door admitting the passage of a bed, or of patients being carried in who are wearing elaborate orthopædic apparatus, such as abduction frames. This room should be large, at least 20 by 20 feet, lofty, efficiently ventilated, easily and completely darkened when required. The floor is preferably of wood ; the walls and ceiling painted, or papered, red, black, or a dark green ; fitted with electric lighting, and provided with steam radiators for the purposes of heating.

It is a mistake to have this room on the small side ; there should be ample space all round the X-ray table, space large enough to allow of

a bed being brought in from a ward, space to allow of patients fixed in the various forms of orthopædic appliances being moved freely about.

3. **The Dark Room** in which all the purely photographic processes are carried out should be large, well ventilated, and fitted with heating arrangements. It should be either near to, or opening from, the X-ray room, and in the latter case the door and adjoining walls must be made X-ray proof. A good wooden floor is the best. The usual developing slope, washing tanks with hot and cold water, drying racks, and so on, must be on a scale large enough to permit of rapid work with large numbers of the larger sizes of photographic plates.

The X-ray Apparatus.

In the consideration of the choice of apparatus due regard must be paid to the nature of the work and its demands. It will be found to be advantageous, in the first place at any rate, to screen all cases from below, and the exact localization of foreign bodies has to be provided for. In addition stereoscopic radiography is essential, whilst limbs have to be radiographed in two directions without moving the patient. Limbs must also be examined when fixed in elaborate splints and orthopædic apparatus—even in plaster. Additional arrangements have to be made so that cases can be radiographed in bed and in the various wards of the hospital.

1. **The X-ray Generating Apparatus** may be either a coil outfit or a transformer on the Snook principle. There are certain advantages and disadvantages in connexion with either. If the former, a 16-inch coil, with a large mercury interrupter fitted with an inverse current rectifier, should suffice. Coil and break can be conveniently fitted to a wall, or on to an upright cabinet stand. The apparatus should be fitted with a trolley type of switchboard, so that the operator can himself control from the position in which he is working. The advantages of a coil outfit are that it permits the employment of almost any type of tube, with care the prolonged screening of any number of successive cases without damage to tubes, large currents are not required, and protection for the operator is easily arranged. A certain disadvantage is—though this is hardly of importance in orthopædic work—that extremely rapid work is not possible, at any rate without the use of intensifying screens. A transformer, on the other hand, allows of very rapid work, but, unless used with a Coolidge tube, does not permit of prolonged screening.

Probably the combination of a transformer and a Coolidge tube is the most efficient of all X-ray generating outfits, but care is required in its use, and the high current used and required in the tube makes for great penetration possibilities, and so adds to the difficulty of effective pro-

tection. The Coolidge tube has the additional drawback that it requires a secondary circuit for the heating of its filament.

Taking all things into consideration, probably at the present time, and working under the conditions set up by the war, if a single apparatus alone is possible, then a good 16-inch coil outfit will be the most satisfactory. This is written with some hesitation, but war conditions made it difficult to get efficient X-ray assistants, and many X-ray departments had to be run without highly skilled expert medical supervision. Under these circumstances the coil outfit is probably in the long run more efficient and considerably less costly than the combination of the transformer and the Coolidge tube.

The Portable Ward Apparatus will consist of a 12-inch coil, mercury break and rectifier, and accumulators giving from 24 to 36 volts, all mounted on a movable stand to the side of which is attached the switchboard. This apparatus can also be arranged to work direct from the ordinary electric lighting circuit if the latter is available. It should be looked upon as for use only in those cases which cannot, either by reason of their general condition or by reason of the risk of moving them, be taken to the X-ray department. Typically, the fractured femur is the case which most frequently demands that the X-ray examination should be made in the ward. X-ray work cannot be carried out in its most efficient manner in an ordinary ward with the patient in bed, and therefore the use of this method should be restricted, and all cases which can be, should be sent down to the X-ray department.

2. **The X-ray Couch.** This is a piece of apparatus of great importance, and should be carefully chosen. If only one couch is used, then it must have fittings which allow (*a*) of screening from below up, and of the localization of the depth of foreign bodies by the triangulation method, with a 10-cm. tube shift in any direction, up or down, or across the table. All this can be arranged for easily with one of the many ordinary tables fitted with a movable tube-box below the top and carrying a rectangular diaphragm. Protection should be ample, especially on the top and on the working side. (*b*) It should be fitted with a compressor and tube-holder to enable plates to be taken from above down, with compression of the part under examination; and this compressor must have a stereoscopic attachment. In actual practice it will be found that a single table, designed with a view to being universal in its application, is a mistake, and that it is advantageous to have two couches, the one designed for work from below up and for localization, and the other for work from above down with or without a compressor and provided with stereoscopic fittings.

3. A large heavy upright **Tube Stand**, with ample tube protection,

and allowing of all movements, is a necessity. Apart from the fact that it will allow of either ordinary or stereoscopic radiography from above down, it permits side views of limbs to be taken after an antero-posterior plate, *without* the necessity of altering the position of the part under examination. This point is one of great technical importance.

4. There are many other **Minor Accessories** of an X-ray plant. It is not necessary in an article of this kind to specify them in detail, but fluorescent screens, localizing screens (such as the Thurstan Holland screen), plate-changing boxes, a stereoscopic viewing box, are amongst the more important required to complete the outfit.

A useful piece of apparatus in the dark room is a reducing camera for the purposes of (1) making prints of reduced size from the large X-ray negatives, and (2) making lantern-slides. By blocking out a window and fixing a plate-holder in it to carry the negative, ordinary daylight can be used, but the most efficient apparatus is one which permits of the use of light reflected from small electric arc lamps.

General Plan of Work.

In large military hospitals, and perhaps especially in orthopædic hospitals, routine and method become of great importance. As a matter of experience, routine and method are often very difficult to obtain.

It is by no means necessary that the expert in charge of a department should do all the examinations himself. A well-trained sister or orderly can carry out all the actual plate-taking, and even localizations, in at any rate the great majority of the cases, and the expert can confine himself to general supervision and direction, the personal examination of special cases, and the filling in of the X-ray reports. It therefore follows that if such an expert is a ‘ whole time officer ’, it is not necessary to restrict his military work entirely to radiography, unless, as is often the case, he is in charge at the same time of several hospital departments. Unless a hospital is isolated by distance, the expert should undoubtedly be put in charge of the X-ray work of a group of hospitals—this of course refers to home service hospitals only ; he should have trained non-medical assistants to carry out routine work, and his work should be the responsibility of seeing that the work of the department is done in a satisfactory manner, and reporting on all the cases from the radiographic standpoint. No responsibility of any kind should be left to the lay assistant, other than the taking of the radiographs, doing localizations under control, and carrying out the technical work of the department.

It should be a rule that the department is open at certain fixed times for the purpose of the examination of cases, and, except in a special emergency, these times should be rigidly adhered to. The reason for this is

that the other work—the development of plates, the making of prints and lantern-slides, and so on—can go on uninterruptedly.

Army Forms. Each case should bring down form W.3172 properly filled in by the attending medical officer. A rigid adherence to this rule will save almost endless friction, and yet experience has shown that officers are curiously lax in respect to these forms. On this form should be stated plainly the exact area of the injury, the reason for the examination, and, as far as is possible, the condition suspected. If it is considered that any special form of X-ray examination other than the routine one is indicated, this should also be stated, together with the reason for the same. The opposite side of the form will be filled in by the X-ray expert, but it must be recognized that in an orthopædic hospital the surgeons are, as a rule, well qualified to read plates and prints, and that consequently elaborate X-ray reports, in the majority of cases, are neither required nor necessary.

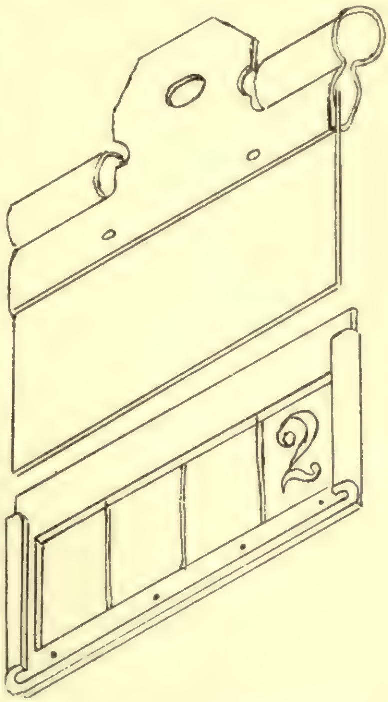


FIG. 238.—Appliance for numbering plates.

The Register of Cases. Army forms A.B.415 and A.B.129, the register and index, should be kept with meticulous exactitude, and associated with this is the necessity for an exact scheme of numbering and storing the plates. Many orthopædic cases are radiographed many times during the course of their treatment, and it is of the utmost importance that the X-ray history should be easily found. Plates can be numbered by the actual X-ray exposure by means of a small device holding metallic figures in an aluminium tray, which will clip on to the edge of the plate outside the paper covering. If these numbers are always attached to the plate at its upper edge, i. e. the edge always nearest to the head of the patient, then the direction of the plate is registered at the same time. (Fig. 238.)

Two points in the carrying out of X-ray work at these hospitals require strong condemnation. One is that, as a general rule, the surgeons insist that the X-ray negatives should always be sent to the wards, and should be kept in the wards with the patient during the latter's stay in the hospital. This means that the plates are kept lying about in the wards,

where the patient's locker, or an odd drawer in a bureau, is the common receptacle. The result is that many plates are broken, some are lost, all are spoilt by various stains and scratches so as to be valueless for future use, and all proper system of filing negatives breaks down.

An unmounted bromide print, with the name, number, and date recorded on its back, attached to the case sheet, is all that is required in most cases, and the actual inspection of the plate by the surgeon is quite unnecessary. Even when plates are sent to the wards, the universal plan of examination is, in the well-lighted wards, to hold them up to the light of a large window—a method which is hopelessly unsatisfactory. Then the X-ray department is informed by the surgeon that such a plate is not a good one and he cannot see what he wants, and this merely because this method of examination and trans-illumination does not happen to be efficient.

The second point is the habit of sending down cases to be radiographed fixed up in plaster of Paris or ordinary plaster, in opaque splints, &c. Apart from its being impossible to define many bone conditions under such circumstances, many such appliances render it impossible to so manipulate a limb as to allow of successful radiography. Under circumstances of this kind it may be possible to indicate the general alinement of a fracture, or occasionally see some rough X-ray point, but beyond this the results are usually disappointing, and it should be recognized that even X-rays have certain limitations.

Technique. As a routine every case should be, in the first place, screened from below up. By careful examination of this kind the large majority of foreign bodies and fractures will be easily seen, and the exact area requiring X-ray demonstration is made evident. Making the diaphragm opening of appropriate size, a plate is placed over the part to be radiographed, and the exposure made from below up. For many cases a record of this kind is all that is required.

It is essential, whatever the nature of the case, that one or more plates should always be exposed. If nothing abnormal is made out on the screen then a plate of the suspected area must be taken, placing the site of injury—or suspicion—in the middle of the plate. Even approximate accuracy of diagnosis is not possible unless this is done as a routine. It is of common occurrence to find small foreign bodies, to find cracks in bone, to find small areas of damage to the surfaces of bones, to find periostitis, &c., which by a screen examination alone would be missed. Even when an obvious fracture or foreign body is seen, a screen examination is not enough for diagnosis alone, to say nothing of record; a plate frequently, indeed almost invariably, shows more than is made out by the screen examination, and affords, especially in the case of fractures, additional information as to the exact condition.

The fact that, in no single case, is it possible to make a reliable NEGATIVE diagnosis from the screen examination alone, cannot be too strongly insisted upon.

It is not necessary to make an exact localization of every foreign body which is seen, but, as a rule, it may be stated that all bullets, rifle or shrapnel, and all of the larger pieces of metal, at the first examination of the case should be localized as a guide to approximate depth at any rate. In those cases, which are very frequent, in which large numbers of small metal fragments are present, exact localization of each piece is unnecessary and hardly feasible, and in such cases stereoscopic radiographs become the best guides.

Putting aside the foreign body question—it is after all not an essential of, but only an incident in, military orthopædic surgery—we find that the X-ray work is practically entirely a question of bones, and of bone conditions; and as, in the other articles, radiographic findings and appearances, &c., must be dealt with by the various authors, any detailed description of these conditions in this article is not called for, and certain broad facts have alone to be considered.

PART II. LOCALIZATION OF FOREIGN BODIES

There are said to be some 250 methods, or modifications of methods, for the localization of foreign bodies, and judging from what appears in some of the instrument-maker's catalogues, this statement appears to be fairly accurate. Many, if not most, of the methods advocated are merely ingenious devices for the performance of an object which can be accomplished by much simpler means, and only serve to confuse the X-ray operator and the surgeons. The ingenuity of the inventors of these methods is little short of marvellous, but as Sir Alfred Pearce Gould said at the end of a discussion upon localization, ' Gentlemen, what the surgeon requires is a simple and efficient method ! '

A method which takes an hour, or even more, to work out on an individual case, however accurate, is of no use when forty, fifty, or even more cases have, of necessity, to be dealt with in a single day's work.

In orthopædic work the large majority of the cases which require localization of foreign bodies will be those in which the foreign body is situated in a limb, there will be a few in which it is in the trunk and involving the spine, but those in the head, face, thorax, and abdomen will seldom be met with.

For routine work I shall describe a simple method, one which has stood the test of four years' work in the 1st Western General, and many attached, hospitals. It has proved satisfactory both to the X-ray department, and, what is even of greater importance, to the surgical staff.

From the very commencement of the war two points in the X-ray examination of cases became impressed upon one as of paramount importance: (1) all cases, without exception, must be screened; (2) all cases, without exception, must have one or more plates exposed upon them. Bullets travel far and lodge in the most unexpected places. One man had an entrance wound in the back, above the scapula, and although there was nothing to indicate that the bullet had traversed the chest, beyond the history of a slight amount of blood-spitting, the bullet was found in the anterior abdominal wall close to the navel. Another had an entrance wound on the outer side of a thigh, and the bullet was discovered in the opposite thigh. A third had a small, punctured wound high up over the right deltoid muscle. It had completely healed, and he was returned to his dépôt as fit for training for overseas. He complained of pain in his back, and stated that the bullet was near the 10th dorsal vertebra. An X-ray examination at the camp hospital was made, and a report given that no bullet was present. Fortunately for the man his company officer was able to send him to Liverpool for further examination, and I found a large rifle bullet embedded in the bodies of the 10th and 11th dorsal vertebræ and transfixing the inter-vertebral disk. The man was discharged from the Army and a gross injustice avoided. Fig. 239 shows a side view of this bullet; a front view also taken showed the bullet shadow lying across the vertebræ. There was no clinical indication in any of these cases as to the position of the bullets, and unless a thorough and extensive screen examination had been made, such bullets would have been missed. These are, perhaps, extreme cases, but they indicate the necessity for these screen examinations.

Plates must always be taken, even when bullets and fractures are seen. In innumerable cases injury to bone will be discovered on a plate which cannot be seen upon the screen, and in a large number of cases small metallic fragments, not seen on the screen, show on a plate. The necessity for using plates in all cases cannot be too strongly insisted upon, even in those where neither foreign body nor fracture is detected on the screen.

The Apparatus. Apart from the generating outfit (already described) the table is the chief consideration. It should be of simple construction; the top should be strong, and wood is better than canvas. It is advantageous to have it broader than is usual, as wounded soldiers cannot be moved about easily, and the examination of the shoulder and hip regions requires ample room. Below the top of the table the tube-box should run easily both longitudinally and transversely. On one side, from the base board carrying the tube-box, should be a strong upright, in the line of the anti-cathode, coming well above the top of the table, and carrying at its top end a bar stretching out across the table top.

The tube-box should be very well protected indeed, especially upon the working side and top, and it should be fitted on its upper surface with a four-sided diaphragm easily adjustable to any size of opening.

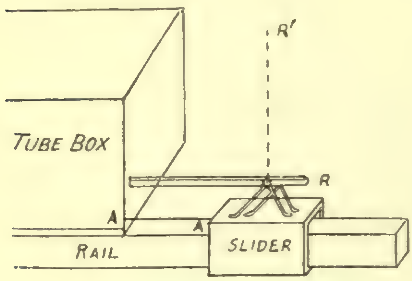
The tube must be very accurately centred by one of the various devices used for this purpose, and then firmly fixed so that it cannot be

FIG. 239.—Bullet embedded in the bodies of the 10th and 11th dorsal vertebræ.

moved. It will be found convenient to have this apparatus so made that the anti-cathode is about 27 cm. in distance from the top of the table. There is nothing to be gained by any movement which allows of this distance being altered.

Along one of the longitudinal bars joining the legs of the table, and supporting the tube-box carrier, a fitting must be attached which allows of an exact 10 cm. displacement of the box (i.e. the tube) in either direction. A fitting of this kind is shown in Fig. 240. The slider, made of

wood, fits accurately to the rail, but slides easily along it. In use, with the pointer R parallel to the rail, the slider is moved along until the end of the pointer just touches the surface of the end of the tube-box. The pointer is hinged so that it can be raised up to the position (R′), and this movement also fixes the slider to the rail. Further, the pointer is so long that when the tube-box is moved from its first position until it impinges upon the slider (that is along the space AA) the movement is automatically 10 cm.



AA = 10 Cms
R. Pointer raised to R′ fixes the slider to the rail.

FIG. 240.

This small fitting allows of the 10-cm. movement to be made with great accuracy, and in either direction of the length of the table, starting from any position of the tube-box; the reverse movement being made by reversing the action of the pointer, &c.

Captain Barclay has described a very simple method for similarly displacing the tube across the table. An oval rod (see Fig. 241) runs through an upright wooden bar attached to the near side of the frame supporting the tube-box, the hole in this upright being between the handle B and a cross wire running through the rod C.

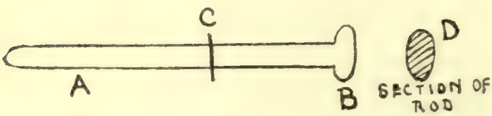


FIG. 241.

Attached to the tube-box itself is a small piece of metal with an oval hole in it slightly larger than the rod. When out of use the long axis of the rod rests in the long axis of the hole in the metal attached to the tube-box, and the box can be moved about independently of the fitting. If, however, a cross-table, measured, displacement of the tube is required, the rod is pushed along through both holes until the handle B jams against the side of the wooden upright fixed to the tube-box carrier. When in this position a half-turn of the rod is made, the long diameter of the rod (it being oval) engages in the short diameter of the hole in the metal attached to the tube-box. This means that the rod becomes attached to the tube-box. Withdrawing the rod means that it carries the tube-box with it, and the rod can be withdrawn only to the point where the cross wire C jams against the wooden upright attached to the fixed frame. The distance of C from the handle is so arranged that when this is done the tube-box has moved exactly 10 cm. By a reversal of this process the tube can be moved in the opposite direction. With these

extremely simple devices, applicable to almost any X-ray table, the 10 cm. tube shift can be easily, rapidly, and accurately made, in any required direction, and from any initial position.

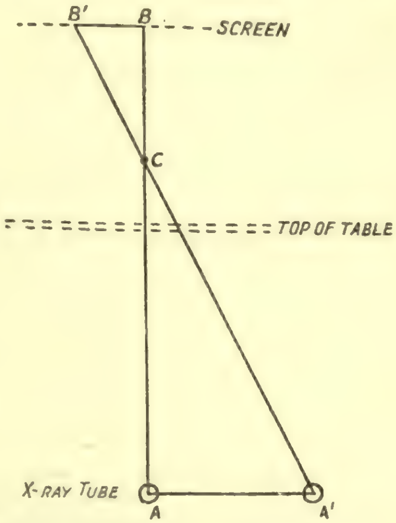
The actual method of localization, which seems to me to meet the difficulties sufficiently well in the vast majority of the cases, is a modification of Mackenzie Davidson's, and has the great advantage that it can be done quickly by means of the screen alone.

This method can be best explained by a diagram (Fig. 242).

A is the point in the X-ray tube from which a central, perpendicular, ray ascends.

B is the point on the screen where the shadow of the foreign body is thrown by this X-ray.

AB may be any fixed distance as long as it is known, or can be measured. For practical purposes, working with an anti-cathode 27 cm. from the top of the table, it will be found to vary—according to the thickness of the part under examination—from about 30 to 50 cm., or from about 12 to 20 inches.



Diagrammatic Explanation of Method of Localization.
FIG. 242.

The apparatus is so arranged (as previously described) that the point A can always be moved to point A′—a distance of 10 cm.—in a straight line at right angles to the upright AB.

When this movement has been made, the shadow of the foreign body will fall on the screen at a point B′, and the distance BB′ will depend upon the position of the foreign body along the line AB.

Now join the points A′ and B′. It is obvious that the foreign body lies upon the line AB at the spot where it is crossed by the line A′B′, namely at C; and that BC is the depth of the foreign body straight below the point B.

We know the distances AB—this can be measured AA′, which is always 10 cm.—and BB′, which can be measured on the screen, and a formula will then tell us the distance BC. This formula is as follows: the distance AB multiplied by the distance BB′, divided by the distance AA′ plus the distance BB′, is the length of BC.

Put this into figures. Let AB be 50 cm., and let us measure BB′ as 2 cm. We know that AA′ is 10 cm. Then 50 multiplied by 2, divided

by 10 plus 2, which is 100 divided by 12, which is $8\frac{4}{12}$ cm., tells us that the spot C, the foreign body, is $8\frac{1}{3}$ cm. below B.

This formula holds good for all distances of AB.

We next come to the **Screen.** In the practical application of this method it soon became apparent that the large fluorescent screens mounted in large frames were impossible for exact work. In many cases these could not be brought into contact with the skin of the area to be examined, and also could not be kept in position. The most convenient form of localizing screen is seen in Fig. 243. A light wooden framework, 6 inches by 2 inches, encloses the screen, the under surface of which is backed by a layer of celluloid or aluminium. On the front is a piece of lead glass in apposition with the fluorescent surface. At a distance of about 1 inch from one end, glass, screen, and backing are pierced by a small round hole, B. Attached to the frame all round is protective X-ray rubber. Along one side of the screen, commencing exactly opposite the centre of the hole, is a centimeter scale, with each centimetre divided into four parts ; on this scale are two movable metal pointers, AA, the ends of which extend half-way across the surface of the screen upon the glass.

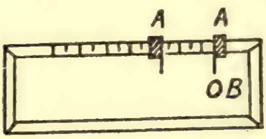


FIG. 243.—Localization screen.

In actual use the screen is laid upon the part under examination, after a preliminary examination with the large screen has shown a foreign body, the longer part from the hole being in the opposite direction to that in which the tube is to be displaced. Experience has shown that a small screen like this can be adapted to almost any position in which localization is required, and the flexible rubber in addition to giving protection to the operator, also helps to keep the apparatus in position.

Before using the small screen, the shadow of the foreign body, or of a prominent part of it, is focused by shifting the tube and manipulating the square diaphragm, so that the central ray throws this shadow in the centre of a small illuminated area of say one square inch. When this is done it means that the foreign body (or the prominent part) must lie on the screen directly in the line of the central X-ray. The next procedure is to replace the large screen by the small one and then manipulate this so that the shadow of the foreign body (or the prominent part) disappears in the hole in the screen. A moistened ink pencil is then passed straight through the hole and a mark made on the skin. It follows that in a perpendicular line under this mark in this position of the part under examination, the foreign body must lie. The tube is then displaced, by the means already described, 10 cm. in the desired direction. The effect of this is to alter the position of the shadow on the screen. The diaphragm, in the direction of the shadow movement, is opened up, and the second pointer

—the first being placed opposite the centre of the hole—is moved to point to the second position of the shadow. The distance between the pointers, as read off on the scale along which they slide, gives the displacement of the shadow, namely BB′, on the diagram.

It is not essential to work from the hole in the screen. After making the skin mark, the screen can be moved, and with the first position placed 1 cm. away from the hole, the first observation can begin from this point. This is sometimes more accurate.

The only other measurement necessary is the distance AB—that is the distance from the anti-cathode to the screen. It should be noted that the great advantage of using the small screen described is that it is in nearly all cases possible to arrange that it lies in apposition with the skin of the patient when the observations are being made, and that for practical purposes the screen and the skin are at the same distance from the anti-cathode. The importance of this point is that no correction has to be made in the depth measurement of the foreign body on account of the screen not being in apposition with the skin.

Captain Oram has suggested a method for the accurate and instantaneous measurement of the anti-cathode screen distance, which has the advantages of extreme simplicity and easy applicability. On the horizontal bar above the table top, which moves with the tube carrier, is fixed a spring tape measure attached to a carrier which allows it to be moved along the bar to any position. The tape in this measure is taken out, cut off, and reversed. It is then pulled down until the figure representing the distance of the anti-cathode to the top of the table—which can be measured—appears in view at the opening in the case of the measure; the lower part of the tape is then cut off so that its end just touches the table top, and a small weight is fixed to this end. It follows that whatever is the distance of the screen touching the skin from the anti-cathode, when the weight at the end of the tape measure is drawn down to touch it, the figure showing at the top end of the tape is the distance in centimetres of the anti-cathode to the skin, i. e. the distance AB on the diagram.

This entire process can be carried out in less than two minutes, and supplies all the data required to estimate the depth of the foreign body beneath the skin mark.

In order to avoid the necessity of a mathematical calculation in each case, I have worked out, and drawn up, two tables of distances; by referring to one or the other of these the depth can be read off in each case (Figs. 244 and 245).

For convenience in working, each centimetre on the scale attached to the side of the localizing screen is divided by marks into four parts, and on the distance charts the depth measurements are worked out for these

DISTANCES OF ANTICATHODE TO SCREEN IN CENTIMETERS

DISTANCES OF DISPLACEMENT OF SHADOW OF FOREIGN BODY

	50	49	48	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32	31	FRACTION TO BE ADDED OR SUBTRACTED FOR EACH CENTIMETER OF DISTANCE MORE OR LESS.
1/2	2 8/21	2 7/21	2 6/21	2 5/21	2 4/21	2 3/21	2 2/21	2 1/21	2	1 20/21	1 19/21	1 18/21	1 17/21	1 16/21	1 15/21	1 14/21	1 13/21	1 12/21	1 11/21	1 10/21	1/21
1	4 6/11	4 5/11	4 4/11	4 3/11	4 2/11	4 1/11	4	3 10/11	3 9/11	3 8/11	3 7/11	3 6/11	3 5/11	3 4/11	3 3/11	3 2/11	3 1/11	3	2 10/11	2 9/11	1/11
1 1/2	6 12/23	6 9/23	6 6/23	6 3/23	6	5 20/23	5 17/23	5 14/23	5 11/23	5 8/23	5 5/23	5 2/23	4 22/23	4 19/23	4 16/23	4 13/23	4 10/23	4 7/23	4 4/23	4 1/23	3/23
2	8 4/12	8 2/12	8	7 10/12	7 8/12	7 6/12	7 4/12	7 2/12	7	6 10/12	6 8/12	6 6/12	6 4/12	6 2/12	6	5 10/12	5 8/12	5 6/12	5 4/12	5 2/12	2/12
2 1/2	10	9 20/25	9 15/25	9 10/25	9 5/25	9	8 20/25	8 15/25	8 10/25	8 5/25	8	7 20/25	7 15/25	7 10/25	7 5/25	7	6 20/25	6 15/25	6 10/25	6 5/25	5/25
3	11 7/13	11 4/13	11 1/13	10 11/13	10 8/13	10 5/13	10 2/13	9 12/13	9 9/13	9 6/13	9 3/13	9	8 10/13	8 7/13	8 4/13	8 1/13	7 11/13	7 8/13	7 5/13	7 2/13	3/13
3 1/2	12 26/27	12 19/27	12 12/27	12 5/27	11 25/27	11 18/27	11 11/27	11 4/27	10 24/27	10 17/27	10 10/27	10 3/27	9 23/27	9 16/27	9 9/27	9 2/27	8 22/27	8 15/27	8 8/27	8 1/27	7/27
4	14 4/14	14	13 10/14	13 6/14	13 2/14	12 12/14	12 8/14	12 4/14	12	11 10/14	11 6/14	11 2/14	10 12/14	10 8/14	10 4/14	10	9 10/14	9 6/14	9 2/14	8 12/14	4/14
4 1/2	15 15/29	15 6/29	14 26/29	14 17/29	14 8/29	13 28/29	13 19/29	13 10/29	13 1/29	12 21/29	12 12/29	12 3/29	11 23/29	11 14/29	11 5/29	10 25/29	10 16/29	10 7/29	9 27/29	9 18/29	9/29
5	16 10/15	16 5/15	16	15 10/15	15 5/15	15	14 10/15	14 5/15	14	13 10/15	13 5/15	13	12 10/15	12 5/15	12	11 10/15	11 5/15	11	10 10/15	10 5/15	5/15

CHART TO SHOW VARIOUS DEPTHS OF A FOREIGN BODY
FOR A TUBE DISPLACEMENT OF 10 CENTIMETERS

C. Thurstan Holland

FIG. 244.

DISTANCES OF ANTICATHODE TO SCREEN IN CENTIMETERS

DISTANCES OF DISPLACEMENT OF SHADOW OF FOREIGN BODY

	50	49	48	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32	31	FRACTION TO BE ADDED OR SUBTRACTED FOR EACH CENTIMETER OF DISTANCE MORE OR LESS
1/4	1 9/41	1 8/41	1 7/41	1 6/41	1 5/41	1 4/41	1 3/41	1 2/41	1 1/41	1	40/41	39/41	38/41	37/41	36/41	35/41	34/41	33/41	32/41	31/41	1/41
3/4	3 21/43	3 18/43	3 15/43	3 12/43	3 9/43	3 6/43	3 3/43	3	2 40/43	2 37/43	2 34/43	2 31/43	2 28/43	2 25/43	2 22/43	2 19/43	2 16/43	2 13/43	2 10/43	2 7/43	3/43
1 1/4	5 25/45	5 20/45	5 15/45	5 10/45	5 5/45	5	4 40/45	4 35/45	4 30/45	4 25/45	4 20/45	4 15/45	4 10/45	4 5/45	4	3 40/45	3 35/45	3 30/45	3 25/45	3 20/45	5/45
1 3/4	7 21/47	7 14/47	7 7/47	7	6 40/47	6 33/47	6 26/47	6 19/47	6 12/47	6 5/47	5 45/47	5 38/47	5 31/47	5 24/47	5 17/47	5 10/47	5 3/47	4 43/47	4 36/47	4 29/47	7/47
2 1/4	9 9/49	9	8 40/49	8 31/49	8 22/49	8 13/[illegible]	8 4/48	7 44/49	7 35/49	7 26/49	7 17/49	7 8/49	6 48/49	6 39/49	6 30/49	6 21/49	6 12/49	6 3/49	5 43/49	5 34/49	9/49
2 3/4	10 40/51	10 29/51	10 18/51	10 7/51	9 47/51	9 36/51	9 25/51	9 14/51	9 3/51	8 43/51	8 32/51	8 21/51	8 10/51	7 50/51	7 39/51	7 28/51	7 17/51	7 6/51	6 46/51	6 35/51	11/51
3 1/4	12 14/53	12 1/53	11 41/53	11 28/53	11 15/53	11 2/53	10 42/53	10 29/53	10 16/53	10 3/53	9 43/53	9 30/53	9 17/53	9 4/53	8 44/53	8 31/53	8 18/53	8 5/53	7 45/53	7 32/53	13/53
3 3/4	13 35/55	13 20/55	13 5/55	12 45/55	12 30/55	12 15/55	12	11 40/55	11 25/55	11 10/55	10 50/55	10 35/55	10 20/55	10 5/55	9 45/55	9 30/55	9 15/55	9	8 40/55	8 25/55	15/55
4 1/4	14 52/57	14 35/57	14 18/57	14 1/57	13 41/57	13 24/57	13 7/57	12 47/57	12 30/57	12 13/57	11 53/57	11 36/57	11 19/57	11 2/57	10 42/57	10 25/57	10 8/57	9 48/57	9 31/57	9 14/57	17/57
4 3/4	16 6/59	15 46/59	15 27/59	15 8/59	14 48/59	14 29/59	14 10/59	13 50/59	13 31/59	13 12/59	12 52/59	12 33/59	12 14/59	11 54/59	11 35/59	11 16/59	10 56/59	10 37/59	10 18/59	9 58/59	19/59

CHART TO SHOW VARIOUS DEPTHS OF A FOREIGN BODY
FOR A TUBE DISPLACEMENT OF 10 CENTIMETERS

C. Thurstan Holland

FIG. 245.

quarter centimetres. If in the shift of the shadow of the foreign body on the screen it is found that the second position pointer lies between two of the quarter centimetre marks, then the more distant mark is used. This means a slight over-estimate in the depth of the foreign body, which, when dealing with such large objects as bullets, is no disadvantage—it is always better to over-estimate the depth a little than to under-estimate it.

A point that is not generally known is that the measurement of the distance from the anti-cathode to the skin need not be exact. The charts show that an error of even three or four centimetres in this measurement makes such an extremely small difference in the depth readings that it is negligible.

The only part of the technique which lends itself to any possibility of an error which may be important is the correct placing of the pointers upon the screen scale, i. e. the shift of the foreign body shadow—BB′. Any possibility of this, say in such a case as when there is difficulty in seeing very plainly the foreign body shadow, can always be controlled by a plate observation. To do this a plate is used in the place of the screen, and the first exposure is made in the first position of the foreign body shadow ' with only a small square illuminated '. The tube displacement is made as with the screen, the diaphragm is opened up to its full extent and the second exposure made—these two exposures should be equal. The result is that on the plate two very distinct shadows of the foreign body appear after development, and the distance between can be accurately measured (Fig. 246).

In this figure the shrapnel bullet is lying slightly in front of the crest of the iliac bone, and this radiograph indicates a further point of value in accurate localization. The double shadow of the edge of the bone is shown in addition to the double shadow of the bullet. The extent of the shift of the former can be compared with that of the latter. If the extent of the shift of the bone is less than that of the bullet, then it follows that the latter is deeper than the bone from the skin mark, and vice versa. It is therefore possible to say on which side of the bone the bullet lies. A better example of this is seen in Fig. 247. Here the shift of the foreign body is very much less than that of the line of the great trochanter, and it follows, the plate having been taken with the back of the hip nearest to it, that the foreign body is posterior to the bone.

In the four years' experience in the X-ray department of the 1st Western General Hospital, whenever a double-plate exposure has been made it has never necessitated any correction of the screen measurements, and thus the accuracy of the screen method when carefully carried out has been proved.

All practical methods of localization up to one point are necessarily the same. A screen examination must be made to determine the presence of a foreign body. After this has been done, two minutes suffice, by the means described, to finish the observations in the vast majority of cases, to mark a spot on the skin beneath which the foreign body lies, and to give its exact depth.

From the point of view of the surgeon his difficulty is 'that at the operation the exact X-ray position of the body must be accurately

FIG. 246.—Double exposure on plate with shift of tube.

reproduced'. This difficulty can be, to a large extent at any rate, overcome by having standard positions for the various parts.

For the lower limb the standard position is that the man lies extended upon his back with the legs side by side, the inner sides of the feet touching one another, and the toes pointing straight upwards ; or, he lies face down with the legs together and the toes pointing downwards over the edge of the table.

For the trunk he lies either on his back or face down, the position of the limbs being accurately noted, but as a rule with the legs together and the arms close to the sides of the body.

The upper limb presents more difficulties in the adoption of standard positions, but these can usually be overcome. The man lies on his back on the table with the arm lying straight out with the hand either palm up or palm down, according to circumstances, a careful note being made

as to this point. It is also necessary to measure and record the angle the upper arm makes with the side of the trunk.

With the forearm the man should lie on his back on the table with his arm at the side and with his hand either palm up or palm down.

FIG. 247.—Double exposure on plate with shift of tube.

Again it is necessary to record the position of the hand, the angle of the elbow, and the angle of the upper arm with the trunk.

In all cases on the X-ray report, full details should be entered as a guide for the surgeon, and to eliminate, as far as is possible, any chance of an error.

In all cases in which standard positions are not possible, then (1) either the surgeon who is to operate should see the localization done and so make himself acquainted with the exact position of the part under

examination, or (2) drawings and a very accurate description should be attached to the X-ray report.

Any deviation at operation from the X-ray localization position will almost invariably lead to difficulties, and not seldom to failure to find the foreign body.

It is not claimed that localization by a method such as that described, or by any similar method, is infallible in the sense that the result will be that all foreign bodies can be easily found and removed, but there is no doubt, from our experience, that from a practical point of view this method, controlled in certain cases by plates in different planes, stereoscopic radiographs, and other devices, as occasion required, has resulted in 99 out of every 100 foreign bodies in which operation has been considered desirable, being found and removed.

When failures occur, two main causes may be suggested as those usually to blame: (1) that, from the nature of the foreign body, its position as regards important structures, the technical surgical difficulties involved, no attempt at removal should have been made. The failure to find in such cases is not the fault of the X-rays or the radiologist. (2) The second cause is faulty operative procedures. Certain surgeons are adepts at finding foreign bodies; they attend the X-ray department and make themselves thoroughly conversant with the technical details of an X-ray localization; they see and note the exact position of the limb and body when such a localization is carried out, and not content with mere depth alone they consider this in relation to anatomical structures, use Symington's sectional atlas—a most valuable addition to any military X-ray department—and try to build up in their minds the position of the foreign body as regards its anatomical situation and its relationship to surrounding structures, bone and otherwise. These surgeons, given the additional assistance of graduated probes, and the telephone probe, find most of the foreign bodies sought for with the greatest of ease.

Another type of surgeon is the one who rarely, if ever, visits the X-ray department, who generally considers two X-ray views at right angles to one another 'all that he requires', who is careless altogether as to the reproduction of the X-ray localization position, and who almost invariably begins, with rough fingers, to separate tissues, to look for the foreign body, to wonder why he cannot find it, BEFORE he has gently dissected down to the depth which the X-ray department has reported.

This operator frequently fails, and even when, after a prolonged and anxious search, the foreign body is found, he finds it at a spot remote from the position suggested by the X-ray examination. It is then that all the blame is laid upon the misdirection of X-rays, and none upon the obvious fact of faulty operative procedures. A rough dissection, especially when performed by the fingers, often results in the removal

of a foreign body far from the situation in which it was originally localized.

The questions of the use of directors, such as the Hirtz compass, or of operating under screen control, in view of our experience, need not be discussed. Neither procedure has been found to be necessary. As routine measures in large hospitals dealing with numerous cases, time must be considered, and elaborate methods of localization must be kept for difficult cases only. Whilst, with regard to operating under screen observation, apart from technical considerations applying both to radiographic and operative procedures, it necessitates the continued presence of an X-ray expert, who should be a medical man.

PART III. STEREOSCOPIC RADIOGRAPHY

It is difficult to over-estimate the value of good stereoscopic radiographs when applied to the bone conditions seen in military orthopædics, but their value is very much discounted by the fact that, with rare exceptions, it appears to be impossible to persuade surgeons of the necessity of acquiring the art of viewing such negatives, and, even if they acquire this art, of taking the trouble to visit the X-ray department and see the plates in a stereoscope. The result of this attitude, as a rule, means that this method is neglected, as the radiographer cannot easily translate the plates into a written description, and the plates are more or less valueless in directing the treatment of cases, unless viewed and studied by the surgeon who has the responsibility of carrying out the treatment.

This attitude is to be deplored, as good stereoscopic negatives often disclose conditions unsuspected from the examination of single plates, and always afford exact, and additional, information which cannot be obtained in any other way.

A surgeon frequently, often as a routine, desires two plates taken at right angles to one another. The usual method adopted is to take one view with the limb say lying upon one surface, and then the limb is rotated through an angle of 90° and the second view taken. No doubt the comparison of these two plates gives some additional information, but the fallacies of such a method in the consideration of fractures —and in the exact localization of foreign bodies—are very considerable.

Consider for a moment what happens in the two cases. Say we are dealing with a complicated fracture, and war fractures are very complicated, of the bones of the forearm. The first plate is taken with the forearm lying upon the plate and the hand palm down, and a certain view of the fracture is recorded. Then the forearm is rotated through an angle of 90°, and with the thumb pointing upwards, a second plate is taken. These plates are then viewed together, comparisons drawn, and

deductions made, from the bone appearances. The fact that in rotating the forearm the relative positions of the fractured bones and the comminuted pieces may be, and usually is, entirely altered by the moving of the limb, is overlooked, and a wrong conclusion is arrived at as to the relationship and position of the fractured bones and the loose pieces.

A similar criticism applies to the localization of foreign bodies when carried out in this manner. For example, a foreign body is situated in the fleshy part of the back of a thigh, and with the limb resting on its dorsum and the flesh flattened out an above down radiograph is taken; the limb is then rotated on to its side, and this time the flattening out of the flesh—from the weight of the limb—is in the lateral direction. The two plates are examined and certain conclusions arrived at by measuring the distances of the foreign body shadow from the bone shadows, and from the edges of the flesh shadows, quite regardless of the fact that owing to the different manner in which the flesh is flattened out in the two positions the position of the foreign body must be materially altered with regard to either. Many surgeons have a rooted idea that such radiographs give a much more reliable indication of the position of a foreign body than does any other method of localization, and the result is frequently a difficult, and sometimes a disastrous, search, ending in a failure. Two so-called views at right angles, to be of any value as an exact representation, must be taken without any movement of the part under examination, and must be made by altering the positions of the tube and plates only. A possible exception is that of a foreign body situated inside a bone, in which case movement of the limb is not of the same vital importance.

No elaborate apparatus, or additional apparatus, is required in the technique of making stereoscopic plates. The essentials are a means of placing successive plates in exactly the same position, and arrangements for allowing of the measured displacement of the tube. The former can be done by means of one of the plate changing boxes supplied by instrument-makers, but very little ingenuity on the part of the operator, in the absence of such a box, will enable this plate changing to be carried out satisfactorily.

The displacement of the tube 6 cm., i. e. 3 cm. on each side of the central spot of the plate, is a simple matter whether the tube is fixed in an ordinary tube stand or in a movable box, and the process is applicable whether the radiographs are made from above down, from below up, or laterally.

For viewing the negatives they can (1) be placed side by side in a window, or in a viewing-box artificially illuminated, and a Pirie stereoscope used; (2) they can be examined in a stereoscope of the Wheatstone pattern. The latter is undoubtedly the most satisfactory and it is easier

to use. (3) If neither stereoscope is available it is not difficult to acquire the art of seeing stereoscopically without any artificial aid, the two plates being placed side by side in a window or viewing-box.

In the very complicated fractures (Fig. 248) seen in military orthopædic

FIG. 248.—Comminuted fracture of lower end of humerus.

hospitals, the amount of exact information as to the position of the ends of the bones, as to the lie of the comminuted fragments and the other details, is extraordinary. In injuries involving the joints the contour of the bones is impressively displayed. In conditions involving the shoulder and hip joints, in which for practical purposes radiographs in only one direction are possible, it is a method of examination which should never be omitted. In cases in which, clinically, necrosis or the presence of actual sequestra are suspected, then it is often the only method of making an accurate X-ray diagnosis. A cavity in the centre of bone can be

differentiated from a hole running into a bone (Fig. 249), a sequestrum can not only be proved to be present, but its exact localization can be determined, when its demonstration by a single plate is quite uncertain. Diseased areas of bone frequently stand out in a manner which is almost uncanny. In the case of foreign bodies—so frequently multiple—the positions of these are portrayed in a wonderful manner whether embedded in a bone, mixed up with the pieces of a comminuted fracture, or in various parts of the flesh. Additional accuracy and information as to site in such

FIG. 249.—Through and through wound of tibia. Sequestra present.

cases can be obtained by placing on the surfaces of the part under examination pieces of metal; marks on the skin are made corresponding to the points where they are fixed; the positions of any foreign bodies in reference to these fixed skin spots is often of great assistance in future operation.

In some cases it is of value to paint the skin round a limb, or on both sides of a limb, with a thick paste of bismuth carbonate and mucilage before taking the radiographs (Fig. 250). The result is that in the stereoscope the skin itself is mapped out with a semi-transparent veil, and the relationship of the foreign body shadows to the bones and the skin on either side is made very clear. I have found this method of distinct value in many cases, and more especially with foreign bodies in the hands and in the tissues of the neck.

PART IV. GENERAL CONCLUSION

In concluding this short description of X-ray work from the view-point of military orthopædics, it is sufficient to enumerate a few of the many conditions in which radiography is of essential value.

FIG. 250.—Foreign body in hand. Skin on each side painted over with bismuth paste.

Bone Injuries. The mere demonstration of bone injury as an aid to diagnosis and treatment is a small though important part of radiographic work ; it is in the after stages of such cases that its value to both patient and surgeon is of such paramount importance. During the whole course of treatment it is possible to watch the bone changes which are taking

place—without any manipulation of the parts the course of healing and the condition of the callus formation can be watched—also the exact position of the ends of the bone and the alinement can be verified painlessly.

We frequently meet with a slow necrosis, either alone or with the formation of a definite sequestrum or sequestra, in war injuries. In the early stages of these conditions, especially in cases where a bone is considerably shattered, it may not be possible to differentiate a definite sequestrum from small pieces of detached bone which are still living and which may eventually become consolidated into the mass of union, and care is necessary in the reading of radiographs when dealing with this point. In the later stages of a wound in which either persistent sinuses are present, or in which healing up and breaking down alternate, then radiography will frequently demonstrate beyond any doubt the size and the definite position of a sequestrum.

Similarly with necrosis. In these later cases, even when no sequestrum is shown, it is a frequent occurrence to see what may be described as a 'fluffy' appearance of the bone at the site of the injury. Irregularity of outline and areas of greater or less density to X-rays; parts of the mass of bone in and around the site of injury to which there is no defined edge; these appearances, when associated with an unhealed and unhealthy wound, are significant of a slow necrosis.

The condition of stumps in amputation cases offers a field to radiographic investigation. Apart from the shape of the end of the bone, a sequestrum can be shown, or, what is of frequent occurrence, the formation of a spur or of spurs; and a necrotic condition of the end, as evidenced by increased translucency, irregularity, and the want of a defined edge, is not at all unusual. Radiography will not only show, but will differentiate these various stump conditions, and on the other hand will in some cases show that the bone itself is not at fault and is in a perfectly healthy condition, a negative piece of information frequently of great value.

After various repair operations, such as plating and wiring of bones, the introduction of bone grafts and other devices for filling up gaps and promoting union, a series of radiographic examinations made at intervals of time often affords the most valuable information as to what is exactly going on.

Finally, there is an interesting condition occasionally met with in which grave joint lesions accompanied by marked bone changes follow after either slight injuries, after no injury at all, or after a septic condition of wounds, and in these cases radiographic examination or examinations are of more than merely diagnostic value.

A short description of three such cases will demonstrate this.

1. Fig. 251 is that of a wrist-joint taken three months after a 'sprain'. With a stiff and swollen joint the radiograph shows general atrophic

bone changes in all the carpal bones and in the ends of the adjacent bones. There was no evidence of any definite bone injury, and there had been no wound.

2. Figs. 252 and 253. The first shows a 'septic arthritis' with a mushy condition of the carpal bones. This followed on a wound remote from

FIG. 251.—Sprained wrist. Septic arthritis.

the wrist, and the radiograph was taken within a few weeks of the commencement of the trouble. Ten weeks later (Fig. 253) shows the regeneration of the carpal bones. The case is interesting as showing the rapidity of the original bone changes, and the equally rapid recovery.

3. Fig. 254. This is a hip-joint condition which occurred without wound or injury, and which clinically suggested sarcoma. The radiograph shows a pathological dislocation with necrotic changes in the acetabulum and head of the femur. This was confirmed by operation. No cause for the condition was found.

FIG. 252.—Septic arthritis of carpus.

FIG. 253.—Same as Fig. 252. Ten weeks later.

FIG. 254.—Disorganized Hip Joint. Sepsis.

SCHEME AND ORGANIZATION OF CURATIVE WORKSHOPS

BY

H.M. KING MANUEL, K.G.

SCHEME AND ORGANIZATION OF CURATIVE WORKSHOPS

The curative workshops were started in October 1916 at the Military Orthopædic Hospital, now the Special Military Surgical Hospital, Shepherd's Bush, W., as an experiment, to judge what results could be obtained.

Fig. 255.—Carpenters' Shop, Special Military Surgical Hospital, Whitchurch, Cardiff.

We organized them on a voluntary basis, having in our minds the main idea that everything possible should be done to do away with the idleness of ordinary hospital life, help the recovery of the wounded, and bring into being a more active life for the patients.

The scheme which I had in mind for a long time was only put into practice owing to the generosity and foresight of the Joint War Committee and the Joint Finance Committee of the British Red Cross Society and Order of St. John of Jerusalem, and also owing to the splendid financial support I received from the public in the different places where the centres have been established.

FIG. 256.—Carpenters' Shop, Special Military Surgical Hospital, Whitchurch, Cardiff.

The history of the department of curative workshops has already been explained several times ; I intend only to explain first the methods employed, and second, the results obtained.

Two classes of methods of treatment in the curative workshops have been used, which have been called respectively : (*a*) the direct curative treatment ; and (*b*) the indirect or psychological curative treatment. The direct treatment requires perhaps less explanation than the indirect, as it consists simply in setting a man to work with his injured limb.

FIG. 257.—Plaster Pylon (Temporary Artificial Limbs) Shop, Alder Hey Special Military Surgical Hospital, Liverpool.

FIG. 258.—Splintmaking Shop, Welsh Metropolitan War Hospital, Whitchurch.

A few examples of this form of treatment given below show the results :

Pte. B. (*Bristol*). Gunshot wound of arm. Wounds healed, but on being sent to the basket shop hand and fingers were perfectly stiff and flexed. After some persuasion he was induced to steady the basket with the injured hand, and becoming interested, gradually used it unconsciously, and in a week he had the normal use of his hand.

Pte. D. (*Tooting*). The most successful basket-maker at this hospital. He had a complete musculo-spiral nerve lesion without recovery. He had an operation for tendon transplantation and now is able to use his hand in a most surprising manner. At basket-making he has trained the transplanted muscles successfully to perform their new duties.

Pte. A. (*Liverpool*). Gunshot wound of thigh—stiff knee-joint. Began work on treadle lathe in March 1917. In June he had easy flexion up to 40°, and dispensed with crutches after three weeks' treatment.

Pte. X. (*Newcastle*). Patient had gunshot wound of right elbow with almost complete stiffness, so that he could not use the arm for any form of work. In the joiners' shop he was first put on to very light work, gradually taking on heavier jobs as the arm improved. Eventually he was discharged from the service, and obtained a post at a good salary in an aeroplane factory.

Pte. C. (*Oxford*). Wounded 11. 4. 18. by bullet through neck to right of cervical spine. There was no use at all in left arm, which was flail-like. Slight movements returned in fingers and shoulder under treatment by massage and electricity on 1. 6. 18. There was power in all groups of muscles but weak and inco-ordinated 24. 6. 18. Work in carpenters' shop then commenced, and in three weeks half normal power with complete co-ordination was established. Other treatment nil.

This form of treatment is ordered by the surgeon directly, and can therefore be considered as theoretically compulsory, but practically it is still voluntary, as the men receive for their treatment encouragement and especially rewards and privileges which stimulate their desire to get better and to work. There is no doubt that even in those cases the results have been great. We must bear in mind that it is of great importance for the man to be able to realize for himself that while he is undergoing his treatment he is doing useful and productive work.

In many cases we have started with the indirect treatment with the object of obtaining a direct result later, that is to say, in cases where owing to the nature of the injury it was not possible to put the man at once on to work where he would have to use his injured limb. This line of treatment has a great importance, as it frequently happens that although a man starts to work only with his sound limb, he gradually brings his injured one into use. To take as an example injuries or wounds of the hands, wrists, or arms, the man will often only use his sound arm at first, but by degrees and very often unconsciously he will begin to help the work of the sound limb with the injured one. This proves one of the

FIG. 259.—Netmaking Shop, Bangour War Hospital, Edinburgh.

FIG. 260.—Plaster Pylon (Temporary Artificial Limbs) Shop, Bangour War Hospital, Edinburgh.

values of the psychological treatment as an initial stage for the direct treatment of an injured limb. Other facts will show, perhaps, still more clearly, from its results, the importance of the indirect treatment.

The curative workshops at the Military Orthopædic Hospital, Shepherd's Bush, soon proved their importance, and it was found necessary to establish them in all orthopædic centres in the country.

The list of trades followed is a very large one, viz. :

Splint making, comprising :
- Metal-workers.
- Fitting.
- Leather-workers.
- Smiths.
- Oxy-acetylene welding.

Painting and sign writing.
Cigarette making.
Motor repairing, including vulcanizing.
Woodcarving.
Machine drawing.
Telegraphy.
Basket making.
Weaving.
Artificial limb making.
Papier mâché work.
Embossed leather work.
Outdoor occupations :
- Gardening.
- Poultry keeping.
- Farming.
- Forestry.

Boot and shoe making.
Surgical boot making.
Carpenters and joiners.
Tailors.
Upholsterers.
Printing.
Photography.
Surgical knife grinding.
Plumbing.
Fretwork.
Bookbinding.
Electrical work.
Net making.
Rug making.
Raffia work.
Cane chair seat making.
Orchestra.
Commercial occupations :
- Shorthand.
- Typewriting.
- Bookkeeping.
- Commercial correspondence.

I give this list only to show the benefit that the great majority of orthopædic cases can receive in our curative workshops by means of the direct treatment.

Several points must be explained in dealing with the methods which have been followed in the organization of the curative workshops. One of the most important was to create an atmosphere of contentment amongst the men who had in a large number of cases been many months in hospital. I had always thought that the best method of creating this atmosphere was to occupy and give work to men who were probably beginning to have in their minds a wrong idea, which for many reasons was so full of harm to them and to the nation. That idea was that the wounded men so often thought they would never again be able to work, or they would never again be able to earn their living when they were discharged from the Army. It seems to me useless to explain the harm that such an idea had, and on the other hand to point out the importance of the fact that those men should have been encouraged to work voluntarily and realize for themselves how wrong they were.

FIG. 261.—Carpenters' Shop, Special Military Surgical Hospital, Shepherd's Bush, W.

FIG. 262.—Splintmaking Shop, Welsh Metropolitan War Hospital, Whitchurch.

Rewards and privileges were given to those working in the shops. This formed an encouragement for them and for the others, and we can state, with a great pride, that in a few weeks after we had started, the morale and atmosphere of the whole place had changed. The idleness of the hospital life began little by little to disappear and one could follow day by day the increase of the activity which had been created.

The system employed was, first, to give occupation to the men; second, to find work which would be most useful for their respective injuries; thirdly, to find occupations which would have a beneficial psychological effect; and fourthly, to consider occupations which would, later on, be of benefit to the men when they were discharged from hospital either to the Army or into civil life.

There is no doubt that the hospitals where curative workshops have been established have assumed an industrious aspect as well as an atmosphere of contentment. From the cases which I have quoted above as examples of the results obtained by the direct treatment, I think its importance is clearly shown. Of course, one must bear in mind that those results would more than probably not have been obtained if the men had not gained interest by their work being productive. The two forms of treatment—direct and indirect—are so intimately connected that I consider it is indispensable to have both methods working together.

To-day, there is for me no doubt that the psychological treatment is more important for the nation. We have to consider the very large number of disabled men we have to deal with. Every possible effort should be made to induce the disabled soldiers or the discharged disabled men to undergo their training combined with treatment. A good result for the men and at the same time for the country will only be obtained if the men realize for themselves the benefit they will obtain for their injury by the treatment, and for their life by the training, which will obtain for them a new trade, where the nature of their wound or injury prevents their return to their pre-war occupation.

One of the chief points aimed at is to get the men to realize the benefits they can obtain from their work. These benefits can be classed under two heads, viz.: (1) the mental benefit, and (2) the indirect benefit to the man's disability. There are, of course, many cases where, owing to the nature of the disability, it is impossible to give the man an occupation where he can use his injured limb. In these cases we had to consider that it is highly desirable, both from a military and a civil point of view, that the general condition of the man should be improved, and by degrees he should be persuaded to lead again an active life. To attain that end in these cases it is needless to explain that it is absolutely essential to have the psychological treatment entirely voluntary, because otherwise

FIG. 263.—Curative Workshops, Bellahouston Hospital, Glasgow.

FIG. 264.—Basketmaking Shop, Special Military Surgical Hospital, Bristol.

it would be practically impossible to get the men to realize for themselves the benefits they would obtain.

With the help of the curative workshops we were able to get men better or fit for the Army much more rapidly than before, as we were able to improve not only the disability from which they were suffering, but also their general physical condition, with a consequent improvement in their mental attitude, which so frequently assumes an unpromising aspect as a result of long-continued suffering in hospital.

The importance of curative workshops from the military point of view was recognized by the War Office, as we have had these workshops installed in all the military orthopædic hospitals. There is also another important side to this aspect of the matter, viz. the economic side. To take the hospital at Shepherd's Bush as an example: the whole of the splints and other orthopædic appliances required for use there are made in the curative workshops, as well as surgical boots, 'Balkan' and 'Sinclair' frames, and many other articles. Moreover, all orthopædic appliances required for pensioners in the London District are made in these workshops, and many splints, &c., are supplied to other hospitals.

It will be realized, therefore, that the curative workshops provide ample scope for the employment of the skill of the patients, and work which is productive always stimulates the interest of the patient to a much greater extent than unproductive work. The fact that their work is productive also gives the patients the feeling that they are doing something which is of great benefit to their fellow-comrades in hospital.

We must now consider the importance of the curative workshop from the point of view of civil life. There is an important connexion between the military orthopædic hospitals and civil life. We have to bear in mind that in consequence of the serious nature of their injury a large number of men are discharged from the Army when they leave our hospitals. We must therefore think of the importance of preparing those men to be again useful citizens when they leave the Army. I think every one will agree that it is very difficult for many men who have been in hospitals for many months, badly wounded, suddenly to resume their civil duties, very often of an active nature, especially if their disability prevents them from returning to their former occupations. This unfortunately has taken place only too frequently, and is one of the reasons why I have done my utmost to enlarge and develop the curative workshops.

In connexion with this side of the question, there is one point which is without doubt of the highest importance. Taking into consideration the fact that many of the disabled men can become useful citizens again, I think it is indispensable that some of their training should begin during the time they are in hospital undergoing treatment. Training and work

FIG. 265.—Artificial Limbmaking Shop, Alder Hey Special Military Surgical Hospital, Liverpool.

FIG. 266.—Smith's Shop, Special Military Surgical Hospital, Shepherd's Bush, W.

may be extremely useful and give good results under medical and surgical supervision, but without that supervision it may do more harm than good, especially at the beginning. The preparation for civil life must begin in hospital, in our curative workshops, where we can have both kinds of treatment and where the men can be under medical and surgical supervision. This is only a beginning, but one which has given results even greater than we expected at first, although there is still much to be done regarding the civil side.

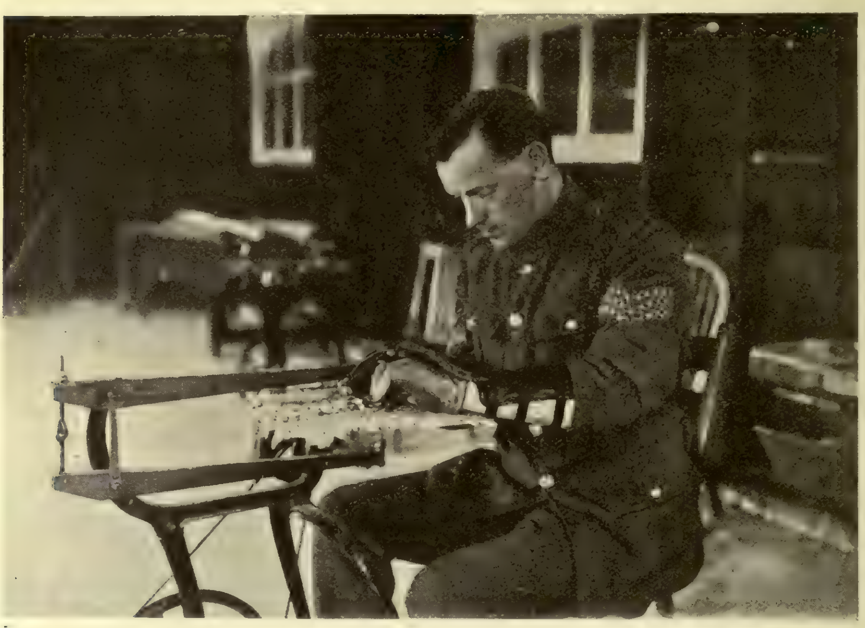


FIG. 267.—Fretwork, 2nd Northern General Hospital, Leeds.

There is no doubt that the link between the military and the civil organization should be enlarged and strengthened. We have to bear in mind the very large number of disabled men, and there is no doubt that everything should be done to create a more complete atmosphere of satisfaction amongst them, and to give them every possible chance of again becoming useful citizens to their country.

The social question connected with the problem of the disabled is for the nation of a capital importance. We have been living in times when brains, strength, imagination, and knowledge have been used for purposes of destruction. They must now also be used for reconstruction—reconstruction of those who have offered their lives to their country and who have been disabled in her cause. One must not forget the needs

of the country not only now but in the future, when useful and skilled workers will be required in all branches of industry. A more complete co-ordination and organization should exist to obtain the results which can still be easily obtained. We have started the organization, we have obtained results, we have done good to the men, we have restored their injured limbs by the direct treatment in our workshops, we have improved their general physical and mental condition by the psychological treatment, we have produced useful work, we have created amongst our patients an atmosphere of satisfaction and industry, we have prepared men for the Army more rapidly than was done previously, we have re-educated those who were to be discharged from the Army—all this has been done and is still being done, I will not say without difficulties, and we have already obtained most wonderful results. My wish is that further organization should create a real link between the authorities and societies which are dealing with the training and professional re-education of the disabled men. We are the first stage of the problem, and I am proud to say that we have established our work on a solid basis.

THE ORGANIZATION AND ADMINISTRATION OF A MILITARY ORTHOPÆDIC HOSPITAL

BY

Lt.-Colonel WALTER HILL, C.B.E., R.A.M.C.,

Asst. Inspector of Special Military Surgery and Liaison-Officer to the Ministry of Pensions;

Late Officer in Charge of the Military Orthopædic Hospital, Shepherd's Bush, London, W. 12.

THE ORGANIZATION AND ADMINISTRATION OF A MILITARY ORTHOPÆDIC HOSPITAL

A MILITARY orthopædic hospital differs in important respects from a general military hospital, as it includes many special departments for treatment, each with its own organization. In this article the requirements of a hospital of 1,000 beds will be discussed.

A. STAFF

The surgical staff of the hospital should be whole-time officers as far as possible, and comprise administrative and surgical officers.

(*a*) **Administrative Officers.** Three officers are essential for administration :

1. The officer in charge, the general administrator, who should possess detailed knowledge of the work of all departments, without having a direct share in the work of any single branch.

2. Registrar.

3. Quartermaster.

(*b*) **Surgical Officers.** (1) *General Staff.*—A hospital with 1,000 beds can best be administered by surgical teams, two or three in number. Each team should consist of a senior surgeon—a specialist in military orthopædic surgery—with two junior surgeons and one anæsthetist.

(2) *Special Staff.*—Medical officers are required for the supervision of the following special departments : radiography, electro-therapy, hydrotherapy, gymnasium, and curative workshops.

The work of the departments dealing with hydrotherapy, electrotherapy, gymnastics, and massage can be so co-ordinated that two medical officers working together can adequately supervise all this work.

One medical officer is required for the control of the workshops, a good administrator with tact, and an interest not only in mechanical work, but also in the patients under his care.

To complete the staff it is highly desirable to have in addition the services of an artist, a modeller, and a photographer.

The officer in charge should see that the special departments are closely co-ordinated and in touch with the general surgical work of the hospital. It is imperative that he and the chief surgeon should visit each department at least once a week, so that they may inspect the treatment given and see that suitable measures are being taken for the improvement or cure of the patient. In relation to the curative workshops

in particular, while their success depends to a large extent upon the efforts of the medical officer in charge of the shops, yet his success can only be obtained by means of the sympathetic co-operation of the officer in charge of the hospital and the principal surgeons. He has a dual relationship, on the one hand to the patients in the workshops, on the other hand to the surgeons in the wards.

B. BUILDINGS AND EQUIPMENT

In addition to the usual hospital buildings a military orthopædic hospital presents certain special features in regard to buildings and equipment.

a. Operative Treatment.

Operating Theatres.—There should be two operating theatres, one for septic, the other for aseptic cases. In relation to the theatre, ample accommodation should be made for anæsthesia, sterilization, stores, and dressing-rooms for surgeons and nurses.

Plastering, Modelling, X-rays. These special departments should be associated with the aseptic theatre, under the same roof if possible. For the X-ray department the requirements are a waiting-room for patients, an X-ray theatre, a dark room and store for plates. The developing room must be quite separate from the X-ray theatre. The plastering room should be in close proximity to the operating theatre, as it is very often necessary to remove a patient from the theatre to the department to put on a plaster. It is of advantage to have the modelling in adjoining rooms ; and the records of models, drawings, and paintings should be in an adjacent room forming the nucleus of an orthopædic museum.

Plaster Department. Three different kinds of work are performed in the plaster department : (1) the fixation of limbs in plaster, (2) the making of casts for shaping splints, (3) the making of plaster splints.

The fixation of limbs in plaster is always done by a surgeon, but the other classes of work are performed by a sculptor's moulder.

Museum. A museum should be formed to illustrate the methods used and results obtained. Plaster casts, photographs, and paintings should be made of all interesting cases, before and after treatment, and should be collected in the museum, with brief notes explaining the nature of each case. Models also illustrating the methods of applying various splints should be shown in the museum.

b. Special Treatment.

Massage.—A ward capable of accommodating fifty beds is needed for massage, equipped with tables, stools, cabinets, sinks, and tubs, with hot and cold water supply. A retiring room with lockers should be pro-

vided for the masseuses, and a consulting room for the officer in charge. About forty operators are needed, each dealing with eighteen to twenty cases a day. All work should be done *coram populo*, without any screens. A few masseurs are needed for special cases. A certain amount of electrical treatment may be given in the massage ward, and when possible the masseuse should continue the electrical treatment of the case to which massage is applied.

Electro-therapy. An area about as large as the massage ward is needed for electro-therapeutics—with office and consulting room (or both massage and electrical treatment may be done in one large room). Each masseuse should be trained in electrical principles, and should deal with her own regular cases.

The War Office provides the following standardized schedule for the outfit of a complete electro-therapeutical department.

Scale of Electro-therapeutic equipment to be provided to Orthopædic Centres. The scale is for the treatment of 250 to 350 patients with, say, 100 out-patients in addition, of which total, it is estimated, 250 will attend the electrical department daily.

Electro-medical apparatus.

	No.
Combined galvanic and faradic tables, complete with metronome, electrodes, and connecting cable	12
Theatre testing electrodes for use with one table	1 set
Portable faradic cells for use in the wards with accumulators or dry cells	2
Radiant heat apparatus :	
„ limb baths	2
„ trunk baths	2
Earthenware arm baths	4
„ leg baths	4
Wooden tables for arm baths	4
Portable vibrators	4
Diathermy apparatus complete with electrode and high frequency fittings	1
Tungsten arc lamp (in special cases only)	1
Couches for massage (supplied in special cases where beds are not suitable)	12

N.B.—Four large sinks with hot and cold water supply should be provided for the electrical department.

Hydrotherapy. A comparatively small equipment is required. The War Office has sanctioned the following standardized schedule :

Scale of Hydro-therapeutic apparatus to be provided to Orthopædic Centres.

Scotch douches with hot and cold water fittings	1 per dept.
Low-pressure massage douches with hot and cold water fittings and, when necessary, wooden couch for reclining patient	2 ,, ,,
Contrast baths (12 ft. long)	1 set per dept.
* Leg baths, simple type with hot and cold water fittings	2 per 250 beds.
* Arm baths, simple type with hot and cold water fittings	,, ,,

* These will not be provided with whirlpool and compressed air fittings.

Paraffin Bath.—For the treatment of many cases a bath of paraffin (melting point 120° F.) has been found efficacious. It can be extemporized at small cost out of an ordinary body bath, heated by steam or hot water. The pipes may be introduced into the bottom of the bath and covered by duck-boarding.

In addition to a bathroom of sufficient size to contain this equipment an office, attendants' room, dressing-room, stores, and a drying room are needed. Tubs in the massage ward can be utilized for a considerable portion of the remedial work of this department. One or two blind masseurs can overtake all the hydro-therapeutical work required in a hospital of 1,000 beds.

Gymnasium. This should be of ample size—60 × 40 ft. × 15 ft. high. An attendants' room, a shower bath and lavatory are also needed.

The War Office has sanctioned the following standardized schedule of equipment :

The minimum amount of apparatus required for a gymnasium 60–70 ft. by 35–40 ft., approximately 15 ft. in height, in an orthopædic hospital of 1,000–2,000 beds is as follows :

15 sets of rib stalls.
4 horizontal beams—measurements 15 ft. × 7 in. × $2\frac{1}{2}$ in.—adjustable heights if possible—with two coco-nut mats each 6 ft. × 4 ft.
1 fixed horizontal bar (important) approximately 7 ft. 6 in. from the ground and $6\frac{1}{4}$ in. in circumference.
2 sets of parallel bars, with 4 mats to each set 6 ft. × 4 ft.
4 sets of gymnastic rings suspended from the ceiling and adjustable in height (important).
8 medicine balls, 4 or 5 lb. each, and 4 from 8–10 lb. each (important).
18 pairs wooden dumb-bells, each dumb-bell weighing 8 oz.
18 pairs indian clubs, each club weighing 8 oz.
2 nautical wheels, adjustable, centre 4 ft. 4 in. from ground.

4 wrist-rolls, with three or more grips of different sizes, with handle at both ends for pronation and supination (important). There should be a fourth grip of very much smaller dimensions, approximately 3 in. in circumference.

6 forms, with adjustable leather clips for attaching to rib stalls. Measurements 12 ft. × 10 in. × 13 in. high.

2 ropes for jumping, with sand-weighted ends.

1 basket or net ball set, comprising two goal posts, nets and 2 balls (important).

1 orthopædic mat for re-education in walking, if possible the whole length of the gymnasium, with three black lines each 2 in. wide and 6 in. apart—measurement between outside lines 18 in.

(The above may be substituted by painting black or white lines on the floor.)

2 ladders each 18 ft. long, 16 in. wide, with rungs 11¼ in. apart and 4 in. in circumference.

The treatment is given in classes, the work being divided into sections—for individual class work, and for general gymnastic work. The former consists of exercises for specific disabilities, while the latter comprises exercises for men who are getting more fit. The tedium of the exercises is relieved by adding to the formal curative work something of the element of sport and play.

Each surgeon should make a weekly inspection of the gymnasium, so that he may note the progress made by his patients.

Curative Workshops. The best design for the buildings is a hollow square, with the office at one side near the entrance, and the smithy and acetylene-welding apparatus either in the centre or on the opposite side from the office. The primary needs of the workshops are for splint-making, the manufacture of provisional limbs, surgical boot-making, cobbling, and carpentry. Other curative or productive crafts depend to some extent on local conditions and the opportunities available for instruction in different trades. The manufacture of baskets, nets, fancy leather goods, rugs, toys, &c., form a most valuable part of many schemes. Other trades which have been developed are printing, cigarette making, painting, horticulture, &c. In the erection of workshops the primary consideration is to have them of ample size.

In the curative workshops treatment falls into two categories—direct and indirect. By direct treatment is meant treatment which has an immediate effect on the man's disability, while indirect treatment is the general mental effect obtained by giving the man a definitely useful occupation. Indirect treatment is of quite as much importance as direct. To ensure that men having useful trades are employed to the best advantage a record of each man's pre-war occupation should be made on

admission to the hospital, and be transmitted to the administrator of the workshops. The surgeon in charge of the patient when sending him to the shops must specify the particular movements by which the man will benefit, while the choice of work is left to the administrator of the workshops, who must take into consideration the previous qualifications and the present disability of the patient.

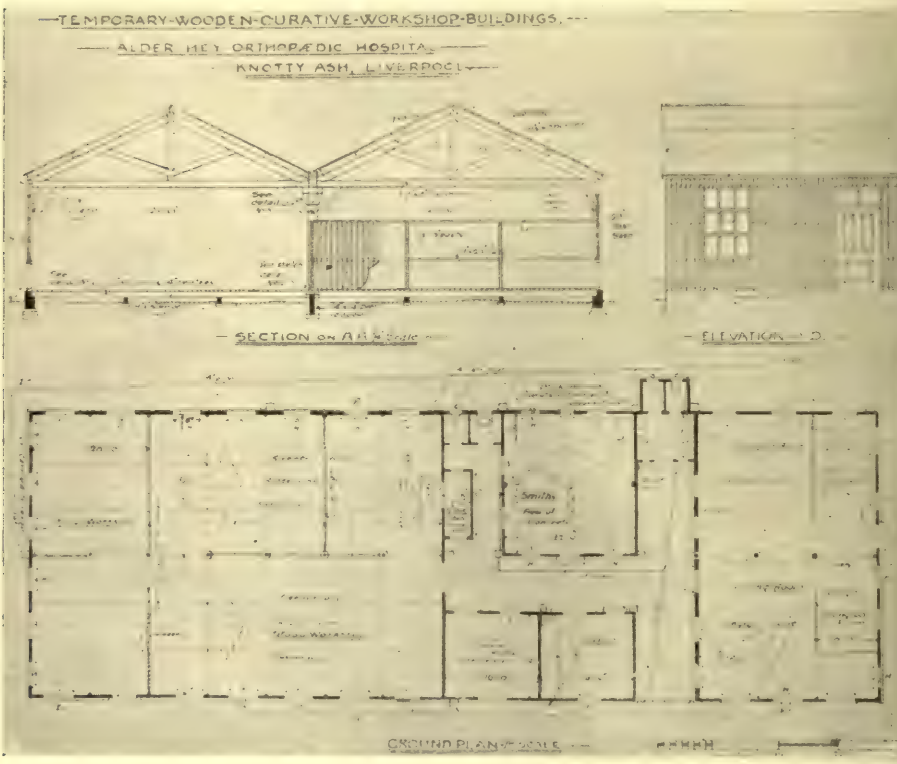


FIG. 268.—Plan of Workshop.

As far as possible every effort should be made to employ patients at their own trade, or, if they are unskilled, or their previous occupation cannot be utilized, to put them to work which will be most useful both to themselves and to their comrades.

Instructors and supervisors in the various shops should be obtained as far as possible from among the patients themselves. The Army Council has arranged that when certain patients are found to be useful for this work they may, under certain conditions, be transferred to the R.A.M.C. for permanent duty in the shops (see A.C.I. 1247/17). If it is found absolutely necessary to employ outside instructors they should

if possible be either discharged soldiers or men above military age, as otherwise difficulties may arise.

The Army Council provides all the material for the workshops, pays the salary of instructors, and generally maintains the shops.

The War Office requires records to be kept of stores and of articles manufactured in the shops, so that a working account may be submitted in a prescribed form each quarter.

Every effort should be made to make the hospital as far as possible self-supporting. To attain this end it is necessary to give the men in the workshops certain privileges, which in all cases should be left to the discretion of the officer in charge. There are special ways of dealing with these men. It is important to remember that in the majority of cases they have had a very trying experience, and have been through a long course of treatment in different hospitals. One must also remember that they are voluntary workers who have come forward to ' do their bit '. What would appear of little importance to a civilian may be a great privilege to a soldier. For example, the time for meals should be studied ; there should, if possible, be a regular distribution of cigarettes ; arrangements should be made for special recreation (theatre, &c.) ; extra passes should be granted to men working a full day of five hours (including treatment) ; a committee, chosen by the men, should be formed to bring forward any grievance before the administrator of the workshops, and through him, if necessary, to the registrar or the officer in charge of the hospital.

These details, small in themselves, tend to promote good feeling and enthusiasm among the men in the workshops, and if they are looked after in this way there is no difficulty whatever in getting them to work regularly and steadily in the shops or at any other work to which they may be put. Patients cannot be compelled to work, but if a strong distinction as regards extra privileges is made between the men who work and those who do not, there will be no lack of applicants for employment.

To enable correct records of all work to be compiled no work should be carried out without a signed requisition. Requisitions should be sent to the administrator of the workshops, who should sign and distribute them to various departments responsible for the work. Any work that cannot be done by the patients should be referred back to the registrar.

Treatment Cards. The patient on admission to the hospital is seen by the orderly medical officer and is sent to one of the wards.

The surgeon in charge of the ward examines the man and then decides what treatment he is to have. If operative treatment is required first, this is duly carried out, but if some other form of treatment is required, the surgeon sends the patient to the appropriate department or departments with his case sheet, and a checking form (No. 1).

CHECKING FORM NO. 1.

MILITARY ORTHOPÆDIC HOSPITAL.

Date............*19*..

MEMORANDUM to Central Checking Office.

The undermentioned patient has been ordered treatment in ....*Department.*

Name..........................*Rank*...........

Reg. No...............

Unit..

Ward...................

Suffering from...................................

....

Signed....................................

MEDICAL OFFICER.

To be filled in by above-named Department.

Please note that the above-named patient will commence treatment on ....*19*..

Signed....................................

In each special department the patient is seen by the officer in charge of the department, who prescribes the treatment and assigns the patients to a masseuse, in the case of electrical, massage, or hydrotherapy treatment, or to a class in the case of the gymnasium. A record card is made out for entering details of the progress of the patient while in each depart-

ment, and the checking form is completed and sent to the Central Checking Office.

At that office an attendance card is prepared for the patient (form No. 2), which he takes with him every time he goes for treatment to the departments, for a record of his attendances to be made on the card. At the end of the day the cards are returned to the Checking Office and examined.

MILITARY ORTHOPÆDIC HOSPITAL, Shepherd's Bush, W.12. **ATTENDANCE CARD.**

NAME.................................. RANK.............. WARD..........................

UNIT.................................. NATURE OF INJURY..................................

Date	MASSAGE			ELECTRICAL			GYMNASIUM			BATHS			INSPECTION		
	From	To	Signature	From	To	Signature	From	To	Signature	From	To	Signature	From	To	Signature
1															
2															
3															
4															
5															
6															
7															
8															
9															
10															
11															
12															
13															

When the treatment in the department is completed, the fact is entered on the man's case sheet, and a form (No. 3) is sent notifying the Central Checking Office.

Checking Form No. 3.

MILITARY ORTHOPÆDIC HOSPITAL.

Date.............19....

Memo. to Central Checking Office.

.......................Department.

Please note that the undermentioned man has now terminated his treatment in this Department. His last attendance was on

....19....

Name .... Rank......... No........

(Signed) ....

Should the patient be a bed case and require electrical or massage treatment, a masseuse attends at the ward with portable apparatus.

In addition to receiving special treatment in the departments, practically every man who is up should work either in the workshops or else-

where, if not as part of his definite curative treatment, then with a view to obtaining the indirect effect by giving him employment.

Card-Checking System. In order to check and ensure the attendance of patients at the various departments for treatment, a card-index system will be found very desirable. Suitable cards should be printed, so that patients may take same with them when attending for treatment and have the fact of their attendance recorded on the card.

At the end of the day it is then an easy matter to look through the cards and trace any defaulters.

Courses of Instruction. Whenever it is possible each military orthopædic hospital should be a training centre. Courses of instruction should be organized to train students and graduates in military orthopædic surgery. The courses should consist of systematic and clinical lectures, demonstrations of selected operations, plastering, modelling, &c. The special treatment—massage, electrical, baths, &c.—should be dealt with in each course. A definite syllabus should be drawn up to cover the whole of the work of the hospital.

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END OF VOL. II.